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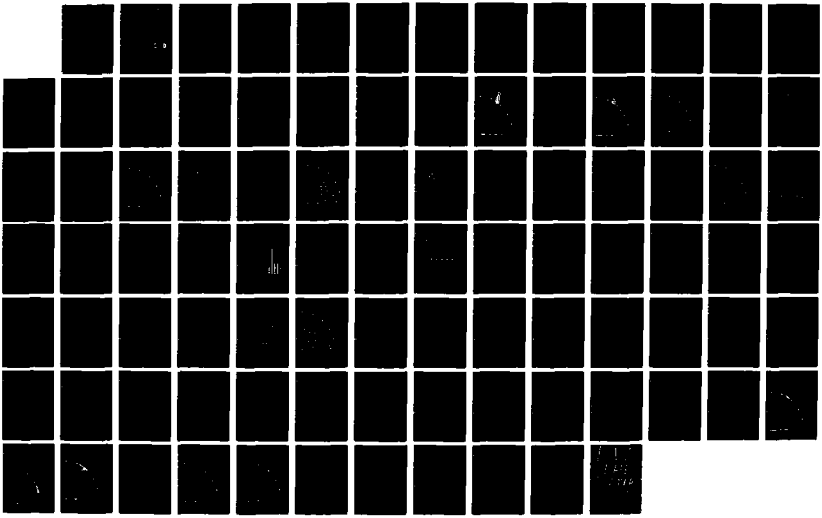

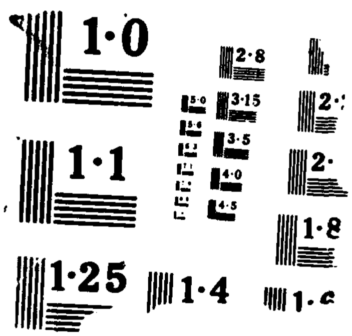
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RULES, SCHEMA, AND DECISION MAKING

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SEPTEMBER 1987

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The development and use of schemata in decision making is examined. Subjects are trained to evaluate alternatives by calculating expected outcomes. In subsequent tests, subjects are required to select the best alternative without being given enough time to compute outcomes. Under these conditions subjects adopted a hybrid decision strategy employing both schemata and approximations to outcome calculation. The schemata were organized around a prototype. They specify a judgment associated with the prototype and also contain feature oriented data useful for accommodating differences between observed situations and the situation prototype.

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There was no evidence for other memory reference structures examined. These included indicator/counterindicator features and wholistic schemata that could entirely replace the learned outcome calculation procedure. There was also no support for memory structures that define discriminator boundaries between different types of judgments or decisions.

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1. INTRODUCTION AND EXECUTIVE SUMMARY

1.1. Overview

This research seeks to characterize the organization of data in memory used in "schema-based" decision making. This characterization is intended to help identify methods to support training, planning, and situation assessment associated with distributed decision making. Of particular interest are methods for presenting information that improve coordination by promoting a more uniform interpretation of situations among decision makers.

Schema-based decision making arises when decisions are based primarily upon situation recognition. In such cases, people recognize that the characteristics of a new situation and decision task match those of previously encountered situations and tasks sufficiently well so that actions that worked in these previously encountered situations are likely to work in the new situation.

We assume that people rely on their memory to recognize the relevance of old situations to new decision tasks. Further, we assume that the data in memory are organized in a particular way that facilitiates the information processing needed for situation assessment. If this organization of data can be characterized, then it may be possible to identify procedures and aids for training, planning, and situation assessment that take advantage of this organization. Such methods should enable people to learn to interpret ambiguous situations more accurately, and should reduce differences in situation interpretations among the members of a distributed decision making team.

This report describes research that examines the organization of data in memory during a decision making task.

1.2. Contribution to distributed decision making

Distributed decision making is a particular type of group decision making. In distributed decision making each member of a group acts individually, making decisions in an area of responsibility or expertise to advance group objectives. Each member must consider not only how his decision may affect his own area of responsibility, but must also consider how it affects the other decision makers and the objectives of the group.

Coordination among distributed decision makers is supported by a plan that specifies the actions to be taken for various possible situations. This plan, which may be developed by the decision makers, specifies the actions to be taken by each decision maker in each of these situations. During the execution of the plan, each decision maker evaluates the situation and decides which of the planned actions is appropriate under the plan or modifies the plan to accommodate unexpected circumstances. Successful coordination depends on a common understanding of the plan and interpretation of the situation among all decision makers, and an ability of each decision maker to accurately assess the impact of a decision on the responsibilities of others. Communications can help each decision maker to interpret the situation the same way

as the others do, anticipate the actions of other decision makers, and estimate his impact on the responsibilities of others.

Poor coordination may arise if different decision makers interpret situations differently, if they fail to seek or communicate essential information, or if they fail to anticipate the consequences of their actions on others. These problems may sometimes be caused by differences in people's expectations about the indicators of possible different situations and the consequences of actions. Such differences may result from differences in the memory data descriptive of the situations.

The work reported here is intended to clarify how information used for situation interpretation is organized in memory. Knowledge of this memory organization can provide a basis for situation assessment aids and for planning and training methods that help all decision makers interpret situation data the same way, help them better anticipate how the decisions of different team members impact each other, and help them to identify information that should be communicated and sought.

1.3. Relationship to previous year's research

During the first two years of research in distributed decision making, Engineering Research Associates developed and tested a schema model of information processing for situation assessment. This model proposed that memory is structured as a hierarchy of "fuzzy" schemata. See Figure 1-1. Each schema contained three layers: a layer for identifying situation features relevant to situation interpretation, a second layer for evaluating, weighting, and combining these features into an overall assessment, and a third layer that specifies actions and inferences appropriate to situations represented by the schema. Data collected in psychology experiments showed that the schema model is able to account for people's situation assessments under the conditions of the experiments.

The research reported here extends the previous research in two different ways. First, it tests the generality of the schema model. Second, it examines the role of the schema not only in situation assessment, but also in decision making.

The generality of the schema model was tested by varying task training methods. In the first year's experiment, subjects were trained to assess situations in a way suggested by the schema model. They were told what situation features were relevant to the situation assessment, and they were presented with situation examples that facilitated their abstracting appropriate feature evaluation and combination methods.

In the current experiments, subjects were not explicitly trained to recognize situations. Rather, they were given a decision task, and were trained to evaluate the possible decision alternatives using formal measurement and mathematical methods. It was hypothesized that with experience the subjects would begin to abandon the rather tedious formal methods and begin to use methods based on recognition. That is, the subjects would begin to use features of situations that would enable them to recognize the superior alternative, and thereby permit them to discontinue using the formal methods. The experimental conditions encouraged this process,

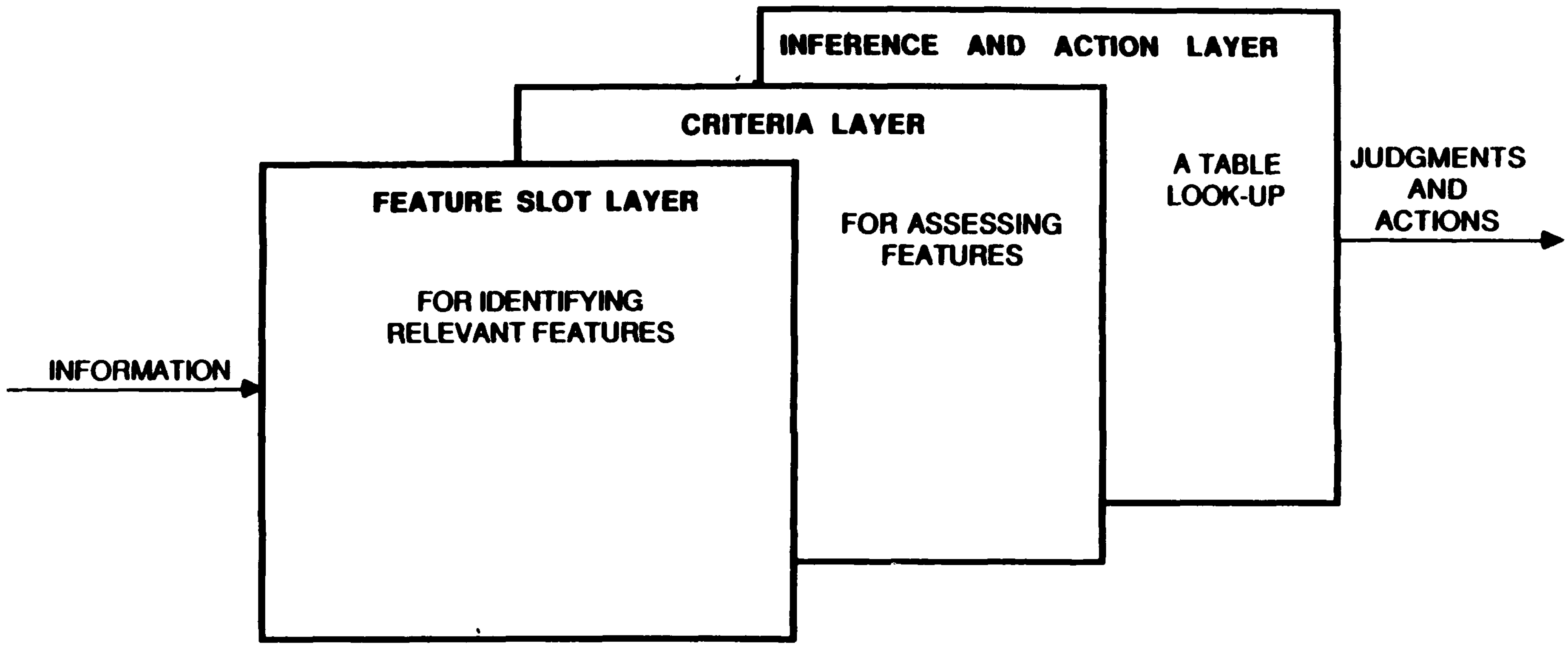


Figure 1-1: Model of fuzzy schema.

by forcing the subjects to evaluate the situation and make their decisions very quickly. The experiments were designed to document the use of memory in decision making and to discriminate among alternative memory models.

The data on decision making performance was intended to document the roles played by two different decision strategies: decision making based on recognition, and decision making based on projecting the consequences of alternatives. In recognition-based decision making, no explicit outcome calculation is necessary. An alternative can be selected because it is known to work in the kind of situation being encountered. On the other hand, indecision making based on projecting the consequences of the decision alternatives, outcome calculation is always required.

1.4. Summary of principal findings

The data from the experiments support seven general conclusions about the formation and characteristics of schemata which support decision making. These conclusions are:

1. Memory data able to support recognition-based decision making will develop from experience with a decision task based on outcome calculation.
2. These data contain more information than just remembered instances.
3. The structure of data in these schemata are consistent with the fuzzy schemata model examined in the earlier experiments conducted at ERA.
4. Memory reference structures that consist of boundaries between different situation classes did not contribute to decision making in these experiments.
5. An overall decision making task may include components of both recognition and outcome calculation.
6. Subjects did not notice or use arbitrary but highly diagnostic indicator/ counterindicator features of the best decision alternatives.
7. Schemata to support recognition of complex situations may develop very slowly, or may not develop at all.

1.5. Organization of report

This report has five additional sections. Section 2 briefly describes alternative models of decision making, reviews previous work in this area, and describes the key issues examined in the ERA research reported here. Section 3 describes the tasks performed by subjects in the experiments, and describes the specific form of memory reference structures investigated for these particular decision tasks. Sections 4 and 5 describe the experiment design, methods, and results for the two major experiments investigating schema-based decision making. Section six is a general discussion and summary.

2. MODELS OF JUDGMENT AND CHOICE

2.1. Benefits from models

This study investigates and models the memory structures that form when people gain experience with an analytical decision task. Models of these memory structures are potentially useful if they provide a theoretical foundation for training, planning, and decision aiding methods based on natural cognitive processes. These methods could enable novices to acquire expert skills more rapidly than current methods do, and could help novices to perceive the essential elements of a planning or decision task, enabling them to see these tasks "through the eyes of an expert."

Larkin and Simon (1987) demonstrated how a model of human cognition and memory organization could support decision aid design. They described how the relative effectiveness of diagrams or text could be understood in terms of a production rule model of knowledge. In this model, knowledge is stored as a sequence of if-then rules. Like Larkin and Simon, we believe that cognitive models can support a theory of information presentation, but we do not assume that production rules are necessarily a good model of memory organization. The experiments described in this report investigate the memory structures that develop in specific decision tasks.

This section briefly reviews the alternative cognitive models that motivated our investigations. These include decision making models, models derived from the literature of schemata, classification, and decision making, and the situation assessment model that ERA recently developed. The concluding discussion outlines the goals of the current research in terms of this review.

2.2. Decision making models

2.2.1. General model

Figure 2.1 (Lawson, 1987) is a general model of decision making. It contains four stages: process, assess, evaluate, and choose. In the process stage, people convert perceptual data into information useful for assessing a perceived situation. The situation assessment, performed in the assess stage, is an estimate of the situation. In a military setting, this estimate includes the location and identification of forces, possible hostile objectives and possible courses of action to achieve these objectives. The next stage, evaluation, is the estimate of how the situation may change. The estimate includes projections of consequences of possible decision alternatives. In the final stage, choice, people compare the consequences of different alternatives and select the best one .

This model encompasses two contrasting models of decision making: rational outcome calculation, and recognition (or schema-based) decision making.

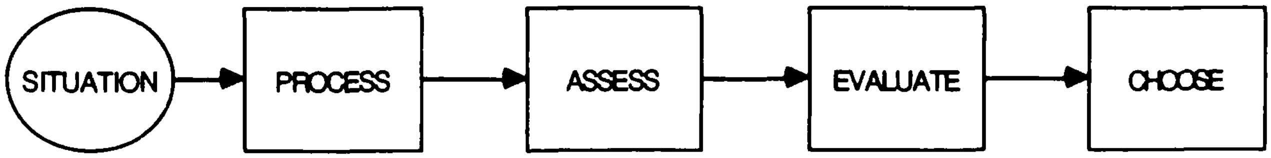


Figure 2-1. General model of decision making.

2.2.2. Rational outcome calculation

The outcome calculation model of decision making looks at decision making as a rational process of explicitly comparing options and choosing the optimal alternative. It emphasizes the third and fourth stages of the general model. It proposes that, to the extent possible, people project the outcomes associated with each alternative, convert each of the outcomes to utilities that reflect the desirability of each outcome, weight the importance of each outomce, estimate a total utility for each alternative, and then select the alternative with the highest utility. Furthermore, the model assumes that the weight attached to an uncertain outcome reflects the probability of that outcome.

Although this model describes some human decision making, as a general model it has two major difficulties: it does not address how the alternatives to be evaluated are identified; and it is inconsistent with well-documented examples of human judgment and choice (Einhorn and Hogarth, 1981).

Some of the inconsistencies between the rational outcome model and human behavior suggest that sometimes people employ a fundamentally different process of decision making. People have been observed, for example, to ignore elementary laws of probability (Tversky and Kahneman, 1983), and their preference (utility) for a bet may depend on whether they are being asked which bet they prefer or which they would be willing to pay most to play (Grether and Plott, 1979). In addition, in some field studies of decision making experienced decision makers rarely consider more than a single alternative (Klein, 1986). Their decisions seem to depend primarily on situation recognition, not on outcome projection and alternative evaluation. Kenneth Hammond (1986) characterizes recognition-based decision making as "intuitive" decision making, contrasting it with the more structured "analytic" rational decision making.

2.2.3. Recognition-based decision making

In decision making based on recognition, people choose a "standard action for a standard situation". The decision seems to follow directly from a recognition of the type of situation and a recollection of what actions usually work well in this kind of situation. For example, one might reason that because a given situation is very much like situation X, then actions Y that usually work well in this situation should be considered.

Recognition-based models emphasize the "process" and "assess" phases of the decision process; evaluation and choice follow immediately from the assessment. In these phases people

characterize the decision task as a kind of decision problem, select a decision strategy appropriate to this kind of problem, and identify promising alternatives. In their 1981 review Einhorn and Hogarth stressed the importance of these processes. They cited research which demonstrates the importance of the mental representations of the decision problem. Different representations of the decision problem are shown to result in different decisions and judgements.

Although people may not be aware of their decision process when basing their decision on situation recognition, the decisions are not random and must reflect considerable (if subconscious) information processing. We believe that recognition-based decision making is based on people's ability to classify situations and employs cognitive methods similar to those used in object classification. These methods are discussed below under situation assessment models.

2.2.4. Hybrid decision strategies

Recognition-based decision making and rational outcome calculation reflect poles of a range of decision making strategies. Many decisions may contain components of both of these modes. Such hybrid strategies are examined by the experiments described in this report.

Three factors influence the relative role played by recognition versus outcome calculation in a decision. These are knowledge or familiarity with the decision task, difficulty of projecting outcomes, and importance of the decision. The more familiar a person is with a situation, the larger the role subconscious classification will play in his decision making. Difficulty in projecting outcomes caused by time or resource limitations or by a large number of *situation uncertainties* encourages a person to rely more on the classification process. Finally, the less important it is that the person make the very best decision, the more likely the person is to rely on subconscious classification.

2.3. Situation assessment models

Two general types of assessment models are important to recognition-based decision making: classification models and schema models. These two types of models, described in section 2.3.1 and 2.3.2, are closely related, but are tailored to explain different types of cognitive tasks. Classification has focused primarily on categorization while schema have been more concerned with understanding. The model developed and tested by ERA contains aspects of both the classification and schema models. It is described in section 2.3.3.

2.3.1. Classification models

The classification model considered here is the "probablistic feature model" (Smith and Medin, 1981). This model assumes that categories are defined in terms of a set of features, but that there need not be any necessary or sufficient feature sets. Rather, classification arises from a weighted sum of features, with each feature weighted according to its importance in the category being considered. If the sum is high enough, then the object is assigned to the category; otherwise it is not.

The role of characteristic properties or features has been explored extensively in the classification research. A feature that is more diagnostic of a certain class (able to discriminate among different classes) is judged to be more typical and more representative of a class even though it may not be a necessary feature. For example, "ability to fly" would be judged more representative and more typical of birds than would "animate" even though all birds are alive and not all birds fly.

Typicality influences judgments and decisions. People judge typical members of a concept more quickly (Rips, Shoben, and Smith,1973; Rosch,1973; Smith,1978) and more accurately (Mervis,1980). Representativeness is not based on a conscious mathematical calculation, but rather on a judgment of feature-based similarity. Representativeness was found to be more consistent with predicted outcomes, while prior probabilities and expected predictive accuracy tended to be ignored (Kahneman and Tversky, 1973). Representativeness can strongly influence probability judgment, and can cause people to estimate probabilities that violate elementary laws of probability(Tversky and Kahneman, 1983)

Classification may depend not only on which features are present, but also on how much each feature is present. Some features can be considered to be present to a degree. Thus, the color "yellow" may be a feature of malaria, with different shades of yellow being associated with different degrees of the malaria feature "yellow". Classification of objects with such features have been modeled using fuzzy sets (Zimmermann and Zysno, 1980). The fuzzy classification of an object, interpreted as the degree to which an object belongs in a class, can be related to the extent to which the characteristics of each of the object's features resembles the characteristics of features expected of objects in the class.

The processes by which features are abstracted and organized into mental structures during category learning are not yet fully understood (Smith and Medin, 1981). It is unclear which features will be abstracted and how they will be cognitively represented. Lewis and Anderson (1985) investigated the development of categories associated with actions chosen in solving geometry problems. They hypothesized that features associated with an action category would be used in selecting an action. Their surface features were like cues paired with specific actions. Subjects who reported noticing the pairings used the cues. Others did not. Lewis and Anderson found no evidence for subconscious learning of the surface features. They found that "necessary" features contributed no more to cateogy learning than did "incidental" features (although the subjects may not have known which features were necessary).

According to Murphy and Medin (1985), subjects need a theory or approach to identify which features matter in classification. Such a theory would dictate to which features people should attend, and may reflect the purpose of a category. In the Lewis and Anderson experiment, subjects who did not use the cues were basing their decisions on something(s) other than what Lewis and Anderson defined as the features.

While Lewis and Anderson did not find support for actions being derived from a feature-based classication process, there is research that suggests the importance of features and classification to action selection when it is impossible to project and compare all possible

outcomes. Chase and Simon (1973) studied the differences between beginning, advanced, and expert chess players. They found that expert players consider fewer alternatives than less expert players and that those alternatives considered by experts tend to be the better ones. Thus, in chess, where complexity precludes projecting all possible outcomes, the expert's knowledge enables him to explore a limited number of possibilities. "Good moves just seem to come to mind."

There is some evidence that the actions ("good moves") came to mind because experts had knowledge structures for categorizing situations and associating types of situations with possible actions. While there were no differences in their abilities to remember other information, better chess players had better memories for chess playing information. The study found that experts tended to process larger 'chunks' of information and the information that was chunked together was related. The errors that experts tended to make in replicating chess positions did not change the functional relationships between the pieces. These observations are consistent with expert chess players' knowledge representations being categories whose characteristic features are based upon the functional relationships between pieces. The experts' ability to replicate chess positions can be attributed to the information in these categories. Thus the expert's short term memory for chess needs only to remember the category and how a particular situation is a variant of that category.

2.3.2. Schemata

Schemata are mental structures that organize knowledge about situations and associated actions. They mediate understanding of social situations and stories and link situations to actions (Abelson, 1981; Bower, Black,and Turner,1979; Graesser, Woll, Kowalski, and Smith,1980; Rumelhart, 1981). They are similar to structures proposed for classification. Each schema contains a number of embedded schema, which function like the features used to classify objects.

Schemata enable observed events to be remembered by "chunking" information. According to the script pointer plus tag hypothesis (Graesser, Woll, Kowalski, and Smith, 1980), observed events are stored in memory by partitioning into typical and atypical parts. The typical part is integrated into existing schemata, so that explicitly stated and inferred actions become "interrelated as a whole". In contrast, a separate and distinct memory tract is constructed for each atypical action.

Pennington and Hastie (1986) showed a very interesting use of schemata in evaluating evidence in a complex decision making environment, juror deliberation. It appears as it jurors evaluated evidence by matching the evidence presented with the evidence that would be expected were various possible crime scenarios true. The jurors seemed to use their knowledge of human behavior to construct these different scenarios (scripts) that correspond to different verdict categories. The verdict judgement may be reached by finding that crime scenario which is most consistent with the evidence.

2.3.3. ERA situation assessment model

Engineering Research Associates developed and tested a model of situation assessment drawn from classification , schemata, and fuzzy set research. Details of this model and of the associated experiments are provided in previous technical reports (Noble and Truelove, 1985; Noble, Boehm-Davis, and Grosz, 1986). The following paragraphs briefly describe the model and experiments.

Figure 2-2 summarizes the proposed memory data and information processing which subjects use to estimate the severity of an "all-out attack" based on the physical characteristics of a picture of this attack.

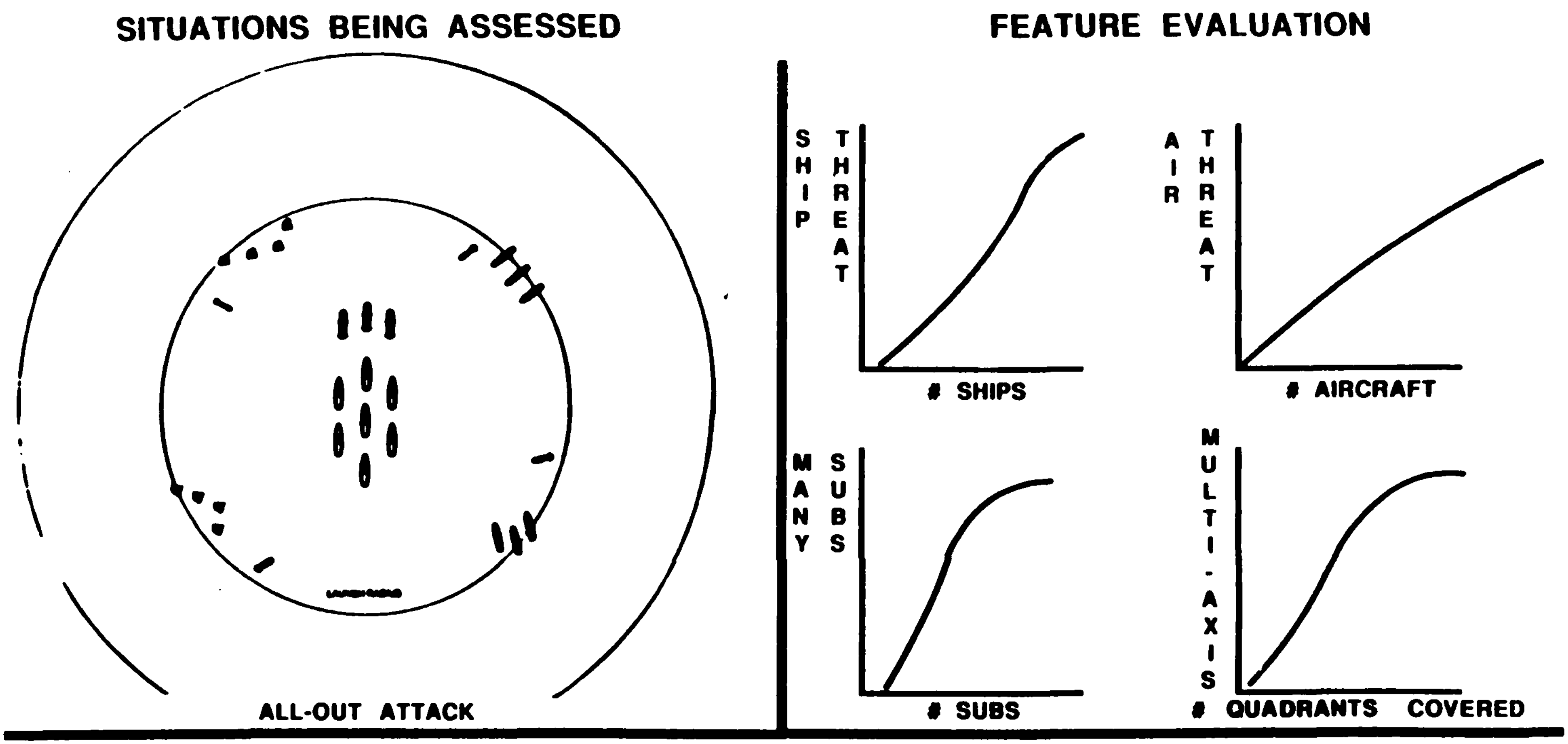
The memory structure is a three layered schema. The first layer defines the features that are relevant to situation assessment. In this case, these are the features relevant to assessing the severity of the attack. There are four features: the number of attacking ships, the number of attacking aircraft, the number of attacking submarines, and the geographical deployment of these submarines. The second layer contains feature evaluation data (upper right quadrant of the figure). These data relate the physical characteristics of the feature to a subjective estimate of how characteristic such a feature is of the situations being modeled by the schema. In figure 2-2, for example, the feature evaluation data for the feature "surface threat" relate different numbers of surface ships to a subjective assessment of how characteristic that number of ships is of a very strong all-out attack.

Figure 2-2 summarizes the three most important information processing steps for situation assessment. Additional steps are described in the ERA technical reports. First, the relevant features are extracted. Second, each observed feature is scored using the feature evaluation data. Third, the feature scores are used to compute an overall all-out attack score. In this example, this overall score is the geometric mean of the feature scores.

This model was tested in a number of psychology experiments. Under the conditions of these experiments it accounts very well for subjects' overall assessments in terms of the physical characteristics of situation features and subjects' subjective feature evaluations.

Because the model worked so well in these earlier experiments, it may prove useful in modeling other types of situation assessment tasks. Before concluding that this is the case, experiments removing the most important limitations of the previous experiment need to be conducted. These limitations are:

1. Subjects were trained "schema-like." They were trained in a way that encourages a memory organization like that of the schema model. They were presented with a sequence of pictures, organized around a "perfect ten" prototype. For each example they were told an experts' assessment and the reasons for this assessment in terms of features (air, surface, and subsurface threat numbers and deployment). They were not told about the model, however, nor were they given numerical feature evaluation data.
2. The experiment task was confined to situation assessment. Subjects were not evaluating the situation for the purpose of selecting among alternatives.



EXAMPLE: SITUATION ASSESSMENT FOR "ALL OUT ATTACK"

1. NOTE FOUR RELEVANT FEATURES: NUMBER OF SHIPS, NUMBER OF AIRCRAFT, NUMBER OF SUBMARINES, AND QUADRANTS COVERED BY SUBMARINES

2. RATE EACH OF THE FOUR FEATURES FOR EXTENT CHARACTERISTIC OF A STRONG "ALL-OUT ATTACK" (SEE CURVES ABOVE)

3. ASSESS THREAT FOR "ALL-OUT ATTACK" FROM GEOMETRIC MEAN OF FEATURE RATINGS.

Figure 2-2: Proposed data and information for assessing all-out attacks.

2.4. Testing the model further

The experiments described below test the generality of the schema model by removing both of these limitations. These experiments examine the memory organization that arises as a result of experience with an analytical decision task. The experiments address these questions.

> If an individual is trained to make decisions based on a complex outcome calculation and rule, will he continue to calculate outcomes forever? Or will he eventually, as he becomes expert, abstract knowledge that replaces part or all of the explicit calculation?
>
> If knowledge that helps with the task is abstracted , then what is the nature of this knowledge, how does it relate to the outcome oriented procedural knowledge, and how is it organized in memory?
>
> What do individuals do when it is impossible to use outcome calculation because of time constraints or resource constraints?

In terms of the situation assessment models discussed previously, these questions are:

1. If people are trained in a decision making task according to the rational outcome calculation model, will they, with experience, evolve toward a recognition-based approach?
2. If recognition-based decision making appears, then what kind of memory structures will arise? How will these memory structures be related to specific instances seen in training? Will they be the beginning of production rules, with specific situation indicator/ counterindicators pointing to an alternative? To what extent will they resemble the fuzzy schema modeled in the earlier experiments?
3. How will the recognition based decision making relate to the outcome calculation decision making taught during training? Will the recognition-based decision making completely displace the outcome calculation decision making, or will pieces of recognition-based decision making become integrated with pieces of outcome oriented decision making?

3. TWO TASKS FOR EXAMINING THE ROLE OF SCHEMATA IN DECISION MAKING

3.1. Introduction

Two experiments were performed to investigate the role of schemata in decision making. In both of these experiments subjects were trained to select an alternative using rational analytical methods. They were not told that alternatives could be selected by situation recognition, but were motivated by the complexity of the analytical method and time pressures to adopt recognition-based methods.

The experiments, which are described in detail in sections 4 and 5, are designed to reveal the role played by memory when subjects select among alternatives in these decision tasks. There are several different memory models possible. This section describes these memory models in the context of the specific decision tasks performed in the experiments.

3.2. Task 1

This task examined the possible memory structures which support relatively simple judgments embedded within a more complex decision task.

3.2.1. Task description

Each subject plays the role of a Battle Group commander who is facing a hostile barrier. He is presented with a situation picture (Figure 3-1). His Battle Group is located at the "X". The ship symbols denotes the locations of hostile ships, and the irregular cross hatched shapes indicate the submarine patrol areas. The subject must choose whether to traverse the barrier along the straight path, traverse it along the curved path, or not traverse it at all, staying where he is. He is given a procedure and simple rule for his decision:

1. Estimate the number of hits your Battle Group will receive from the hostile forces along each path.
2. Pick the path along which you receive the fewest hits, unless this number of hits is more than six. In that case, stay at the "X."

The subjects are provided with precise means for calculating hits from the hostile ships and submarines. The subjects are told that their Battle Group can be attacked by enemy ships only at the black dots. There are three places they can be attacked along the straight path and five places they can be attacked along the curved path. Their Battle Group travels the distance between black dots in one hour. Their Battle Group may be attacked by enemy submarines anywhere along the paths. The computation of hits from submarines has the following steps:

1 Divide each submarine patrol area in half vertically along its right-left center of gravity. If the patrol area were cut out and balanced on a ruler, then this center of gravity is the line where the cutout would balance.

2. Locate the center of gravity for each half of the cutout. This center of gravity is the point where each half would balance on the point of a pencil. Mark this point.

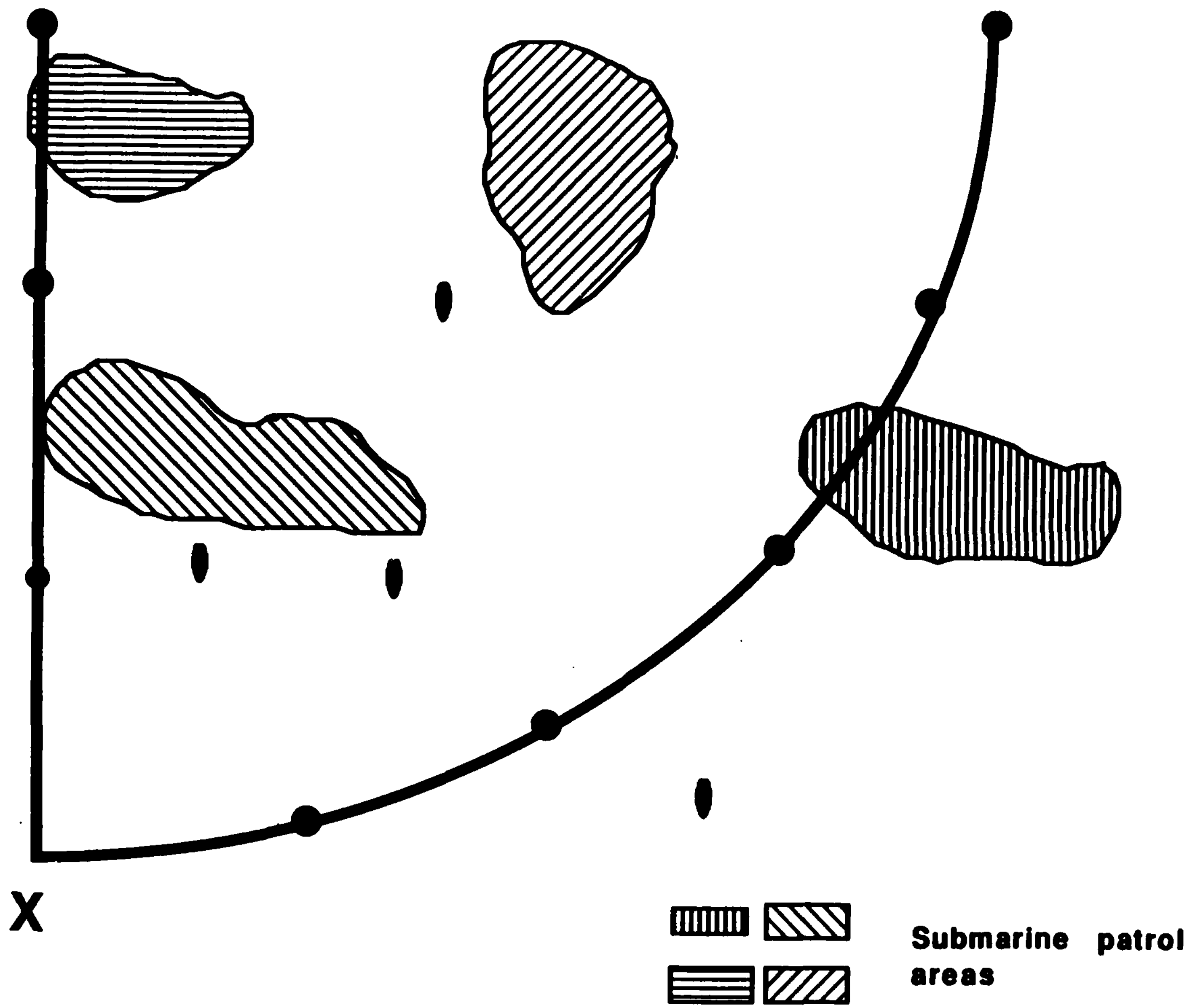


Figure 3-1: Sample picture of barrier situation (Experiment 1).

3. Measure the distance between each of these center of gravity points and the straight and curved paths. Each center of gravity point which is within the threat missile range (shown on the legend of the picture) can score one hit.

The method for calculating hits from the hostile ships is somewhat more complicated. The steps for this computation are:

1. Consider each path in turn.

2. When you select a path, the hostile ships will start to move into positions where they can attack. Fortunately, the hostile ships are slow. In one hour they can move only the "maximum ship movement" (shown on the legend).

3. If after the first hour the ship can move to within the threat missile range of the first dot on the path, then that ship can score a hit. Determine the possible positions of enemy ships after one hour to determine the number of hits, if any.

4. After scoring one hit, a ship may change direction and try to move within the threat missile range of the next black dot along the path.

5. Estimate the positions of ships after the second hour. Those ships within the threat missile range of the second dot can score a hit.

6. Repeat the process for all successive dots along the path.

To help them with their measuring the subjects are given two paper cutouts: a circle whose radius is the threat missile range, and a ruler with divisions marked in units of maximum hourly enemy ship movement. Figure 3-2 shows the movements and measurements needed to calculate the hits from hostile submarines and ships. Estimating the hits from a hostile ship by projecting its future positions was intended to represent scenario projection in decision making.

In order to encourage non-analytic estimation methods, this process was made intentionally complex. The ability of hostile ships to change direction and follow the subject's Battle Group could be confusing, for the hostile ships can sometimes score two hits by moving initially to an area between two hit spots rather than moving directly toward one of them.

It is not actually necessary to consider the different movements of hostile ships in order to estimate the number of hits from that ship. It is possible to estimate these hits entirely from the initial position of the ships. Figure 3-3 shows a set of contour range circles for Experiment 1 that mark the areas of initial positions from which hostile ships can score a hit at various hit points (the large dots along the paths). A ship whose initial position is in one of these circles can score a hit at the hit point at the center of the circle. If a ship is located in two circles, it can score two hits. If it is in three circles, however, it can still score only two hits because once a ship starts moving toward the first circle it can no longer reach the third one in time to score a hit.

The subjects were **not** shown these circles, nor was there any hint given in the instructions or training that such circles exist.

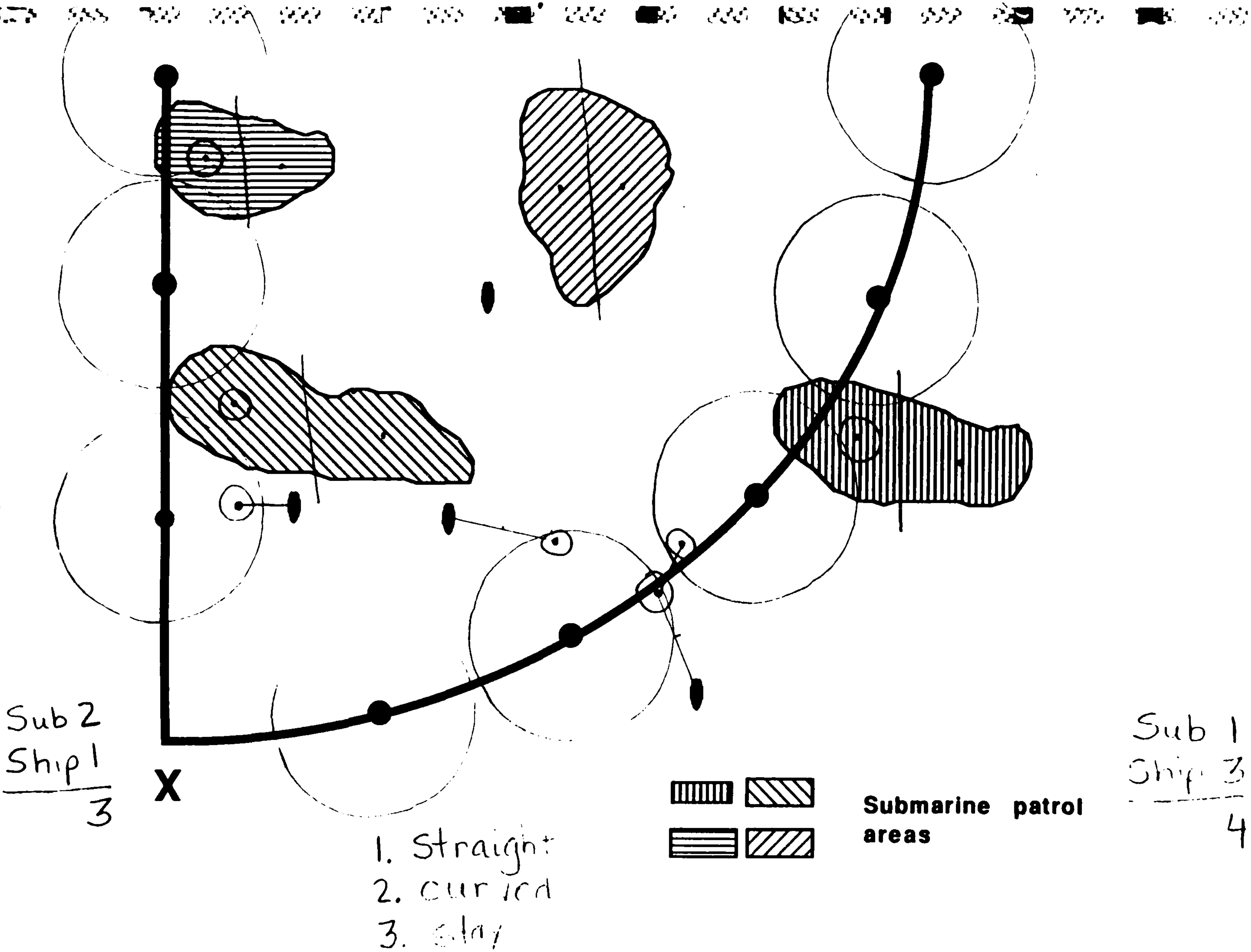


Figure 3-2: Barrier situation picture showing evaluation of ship and submarine hits (Experiment 1).

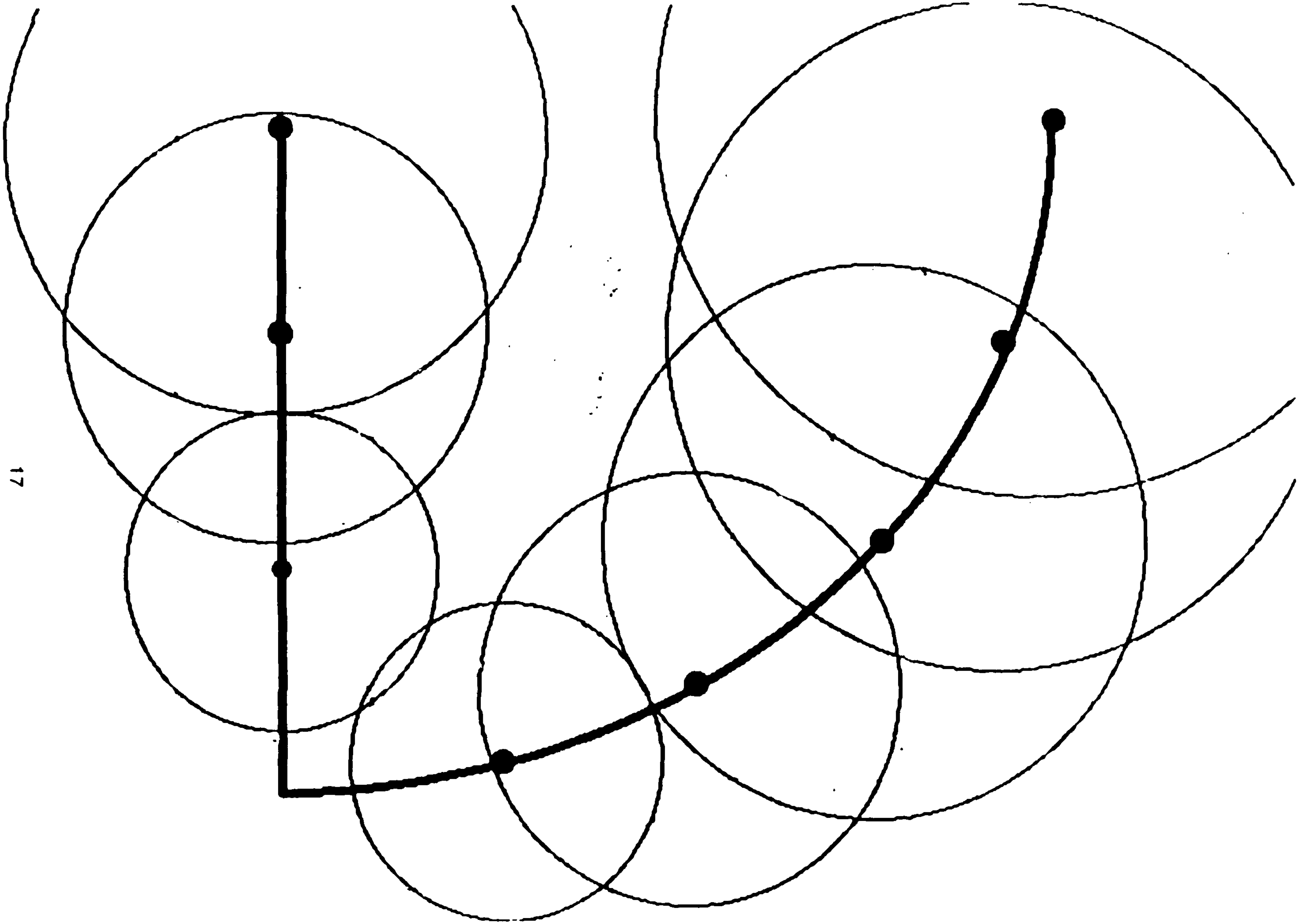


Figure 3-3: Contour circles showing areas from which hostile ships can reach the Battle Group.

3.2.2. Possible memory structures for estimating ship hits

Several different memory structures which could help people estimate whether the straight path, the curved path, or the stay option is the best alternative might develop from experience with this task. These memory structures are: (1) remembered ship locations and associated number of hits; (2) ship schemata consisting of remembered locations and hits plus data for evaluating the significance of location changes; (3) contour lines separating areas from which a ship can score zero, one, or two hits; and (4) indicator/ counterindicator features that are linked to promising alternatives. The first three memory structures could help people estimate the number of hits from each ship. These estimates must then be summed for each path in order to determine the best alternative. The last option could help them to predict the best alternative without having to estimate the total number of hits along each path.

Remembered instances only

When people begin learning this task, they need to project the movements of the hostile ships in order to estimate the number of hits by that ship. As they gain experience, however, they may begin to recognize ships previously seen at particular locations. If they can remember how many hits ships at these locations scored, then they can can estimate the hits from those ships from this memory. They do not have to actually measure the movements of these ships.

The "remembered instances only" hypothesis assumes that a person remembers **only** the number of hits from ships at various positions, and does not know how to modify his estimate for ships at locations somewhat displaced from these remembered locations. A person remembering nothing more than the locations and hit scores of previously seen ships loses his ability to estimate the number of hits when ships are displaced from the locations of previously seen ships. Furthermore, he does not know how to adjust his estimate as a function of the direction or magnitude of the displacement.

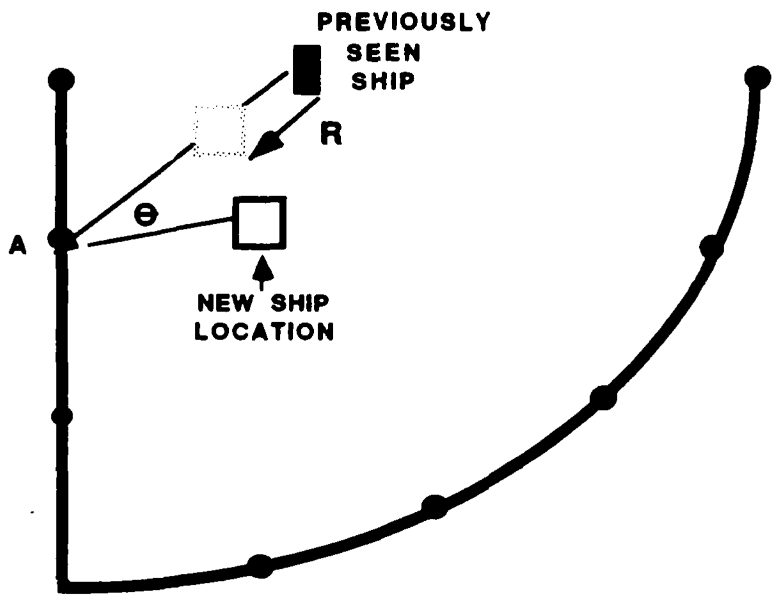
Fuzzy set schema for individual hits

The schema for individual hits generalizes the remembered instances, enabling people to adjust their ship hit estimates as a function of the direction and magnitude of the displacement. The schema for an individual ship hit has the same general structure and contains the same types of information as the fuzzy set schemata described in the earlier ERA reports. In this decision task there would be a different schema for each remembered ship location relative to each relevant hit point. There are many very similar schemata. Each differs from others by only two parameters. The schema enables a person to estimate from visual inspection whether a new ship will be able to score a hit on the relevant hit point. Figure 3-4 illustrates a possible schema for an individual ship. The three layers of the individual ship hit schema are:

1. Feature identification layer. This layer identifies the features that are relevant for estimating the number of hits from a hostile ship close to the location of the remembered ship which is responsible for this schema. These features are derived from the relative polar coordinates of the locations of the new and remembered ships. One feature is the angular displacement of the new ship relative to the remembered ship. The second feature is the radial distance between new and remembered locations divided by the radial distance

Schema Features (used for identification):

R: radial displacement
Θ: angular displacement



Previously seen ship scores a hit at "A"

Feature evaluation data for features R and O

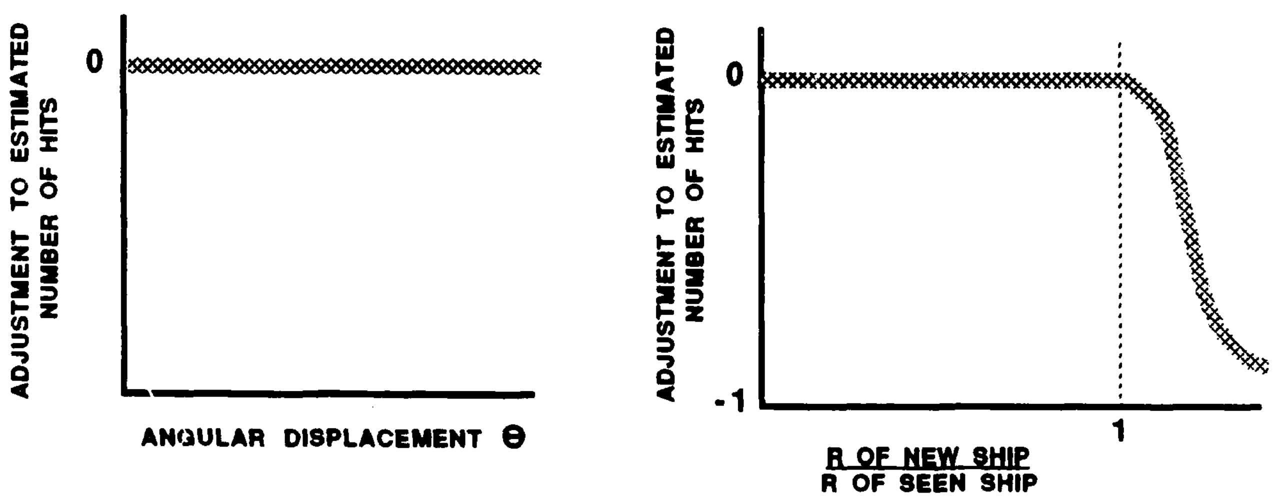


Figure 3-4: Schema for individual ship (Experiment 1).

between the hit point and the location of the remembered ship. The polar coordinates are centered on the ship hit point.

2. Feature evaluation layer. This layer contains the data for evaluating the significance of displacements between the new ship and the remembered ship. It contains two feature evaluation curves: one for the relative angular displacement and one for the relative radial displacement. Figure 3-4 shows the evaluation curves. The estimated number of hits is invariant with respect to angular displacement, but can change with radial displacement.

3. Action and inference layer. This layer specifies whether the new ship will score a hit on the hit point that serves as the origin of the feature evaluation polar coordinates.

Because this is a "fuzzy" schema, the feature evaluation and inference data are fuzzy set curves. For the example of figure 3-4, the feature evaluation data for radial displacement shows no increase for new ships closer to the hit point and a gradual reduction to zero for ships further from the hit point. The steepness of this curve represents how fuzzy the hit-no hit transition point is to the person with this schema. The midway point (adjustment of -.5) represents the point at which this person would be equally unsure whether or not the ship can score a hit. Note that in this example the functional significance of a displacement cannot be inferred solely from its magnitude . Very large angular displacements make no difference. Relatively small outward radial displacements can have a large effect.

Contour lines separating areas of zero, one, or two hits

A third type of memory reference structure are contour decision curves separating the areas of the picture from which a ship can get zero, one, or two hits. Such contour plots are often the basis for computer classification algorithms. These curves are very complex in this experiment, being formed from the arc segments of the circles shown in Figure 3-3. The curves are much simpler in the task 2 experiment, and are shown and discussed further there.

3.2.3. Feature indicator/counter-indicators for alternative selection

According to the ACT theory explained in Lewis and Anderson (1985) as people gain experience with a decision task they may learn to associate features of the situation with preferred alternatives. Experienced people can use these features to make decisions.

In the training pictures for this decision task, special features were associated with preferred alternatives. Two ships side by side to the right of the upper portion of the straight path always indicated that the curved path is best. A single ship outside of the curved path always indicated that the straight path is best. Intersecting submarine patrol areas always indicated that the stay option is best.

People who learned to use these features could very easily select the preferred alternative, for the best alternative is unambiguously associated with the best option.

3.3. Task 2

This task was designed to examine three issues: the use of contour lines for estimating hits from individual ships, the relationship between individual ship hit estimates and alternative selection, and the existence of wholistic path or choice schemata.

3.3.1. Problem description

Task 2 is very similar to the first decision task. Each subject again plays the role of a Battle Group commander who is facing a hostile barrier. In this task he is presented with a situation picture which shows the two paths and the position of hostile ships (Figure 3-5). His Battle Group is located at the "X." Once again the subject must decide whether to traverse the barrier along the straight path, traverse it along the curved path, or stay where he is. He is told to select the path where he receives the fewest hits, unless that number is more than four. In that case, he should stay where he is.

The procedure for calculating ship hits is simpler in this task. A hostile ship can strike anywhere along the path. As the subject's Battle Group moves along the path, the hostile ships move toward the path. When the hostile ship is at the closest point of approach with respect to the subject's ship (both are on a line drawn perpendicular to the path being traversed) then the subject calculates the number of hits by measuring the distance between the hostile ship and the path. Ships within the "two hit" distance of the line score two hits; those within the "one hit" distance score one hit.

3.3.2. Possible memory structures for estimating ship hits

Three memory structures for estimating ship hits are considered: remembered instances only, ship schema, and contour plots.

<u>Remembered instances only</u>

People remember the locations of the ships previously seen and the number of hits scored from ships at these locations. Ships close to the locations of these remembered instances are assumed to score the same number of hits as the remembered instance did. Confidence in this estimate falls as the distance between the new ship and remembered ship increases. This loss of confidence is a function only of the magnitude, but not the direction, of the displacement.

<u>Fuzzy set schema for individual hits</u>

These fuzzy set schema are similar to the ones described for task 1. There are many of these schema, potentially one for each of the locations of the remembered ship locations. Each of the schemata has three layers: one for identifying relevant features; one for feature evaluation, and one for specifying actions and inferences.

Again, the schema is organized around the location of a remembered ship. The number of hits specified by the schema is the number of hits at the remembered location with adjustments specified by the features. The two features for each of these schemata are coordinates for the displacements of the new ship relative to the remembered instance. One feature might be the

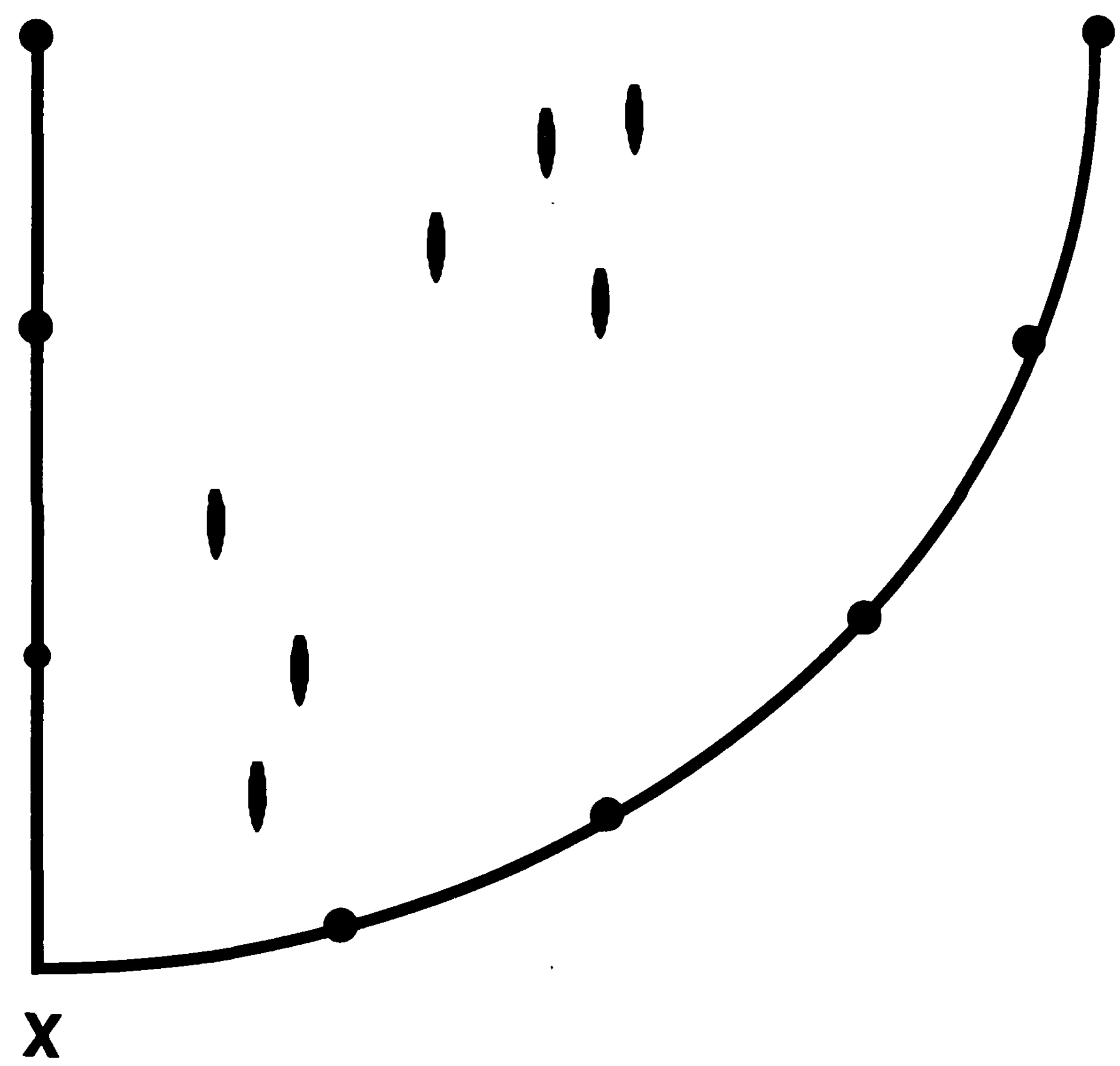
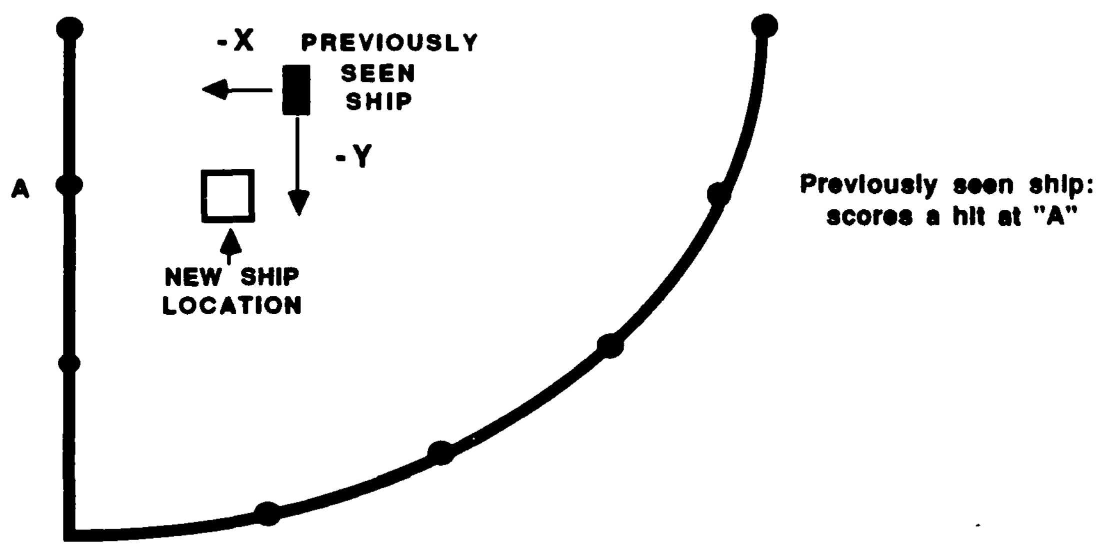


Figure 3-5: Sample picture of barrier situation (Experiment 2).

Schema Features (used for identification):

X: horizontal displacement
Y: vertical displacement



Feature evaluation data for features X and Y

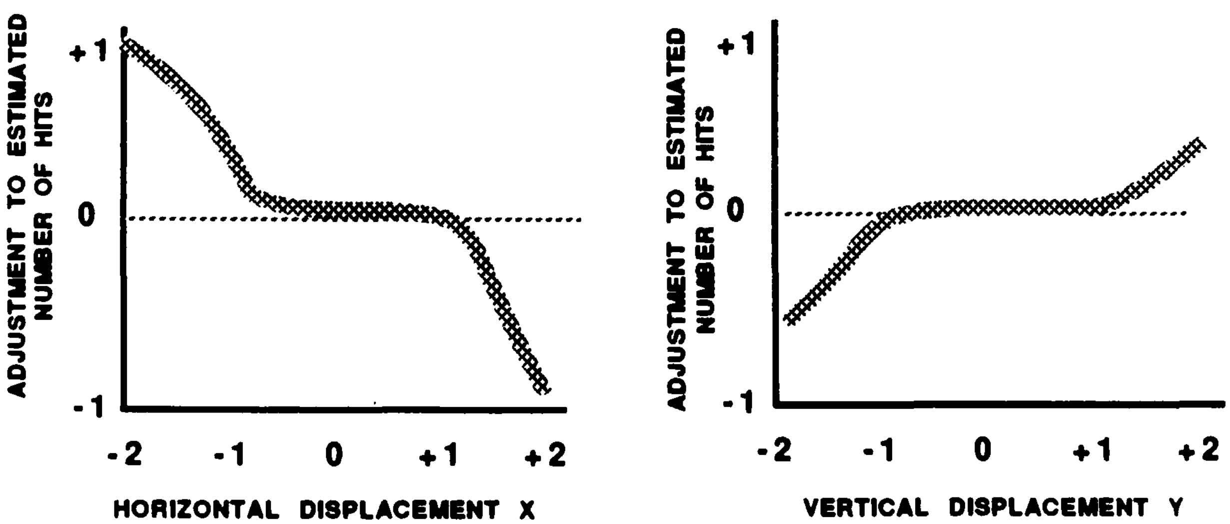


Figure 3-6: Schema for individual ship (Experiment 2).

relative displacement of the new ship parallel to the subject's ship path; the other might be the relative displacement perpendicular to this path. Figure 3-6 illustrates one of these ship hit schemata.

Contour lines separating areas of zero, one, or two hits

Figure 3-7 shows the locations of all of the ships displayed to the subjects at any time in any training or test picture, and shows the contour lines separating the zero, one, and two hit areas. It is possible that during training subjects abstract the positions of these contour lines, and that when estimating ship hits they compare the positions of new ships to the positions of the contour lines.

This memory reference structure is distinctly different from the individual ship hit schema described previously. In the schema case, subjects are estimating the hits from new ships by comparing the location of the new ship with the remembered locations of previously seen instances. They use the feature evaluation data to estimate the impact of the displacement of the new ship on the number of estimated hits. In the contour lines case, subjects are comparing the position of the new ship to the positions of the contour lines. A ship that lies within the inner contour line is estimated capable of two hits; one that lies between the inner and outer contours can score one hit, and one that lies beyond the outer contour cannot score hits.

Subjects basing their ship hit estimates totally on the position of the contour lines would estimate ship hits differently from those using the locations of remembered instances. We assume in the former case that the contours form during training as a generalization of the ship hit measurements, and that after training they have no memory of the locations of the particular ships that contributed to this generalization. In that case, the subject's contours and contour-based hit estimates might have the following characteristics:

1. The contours are "fuzzy." The subjects are not certain of the exact location of the transition line from two hits to one and from one hit to none. As the subjects gain more experience these transition lines get more precise.

2. The location of the contours may be inaccurate and subject to biases. They may tend, for example, to be systematically too close to the ship paths.

3. The accuracy of the subject's ship hit estimates is a function of the accuracy of his contour lines. Subjects with more accurate contours should estimate ship hits more accurarately. Accuracy should depend only on the accuracy of the contours, and not on the proximity of the ship to previously evaluated ships.

4. Confidence in the number of ship hits depends on distance from the subject's contour lines. Subjects should be more confident of hit estimates from ships further from the fuzzy contours than for ships close to the contours. Confidence in ship hits for ships equidistant from the contour should be approximately the same, even if the ships are on opposite sides of the contour. For ships equidistant from the contours, confidence should not depend on the proximity of the ship to previously evaluated ships.

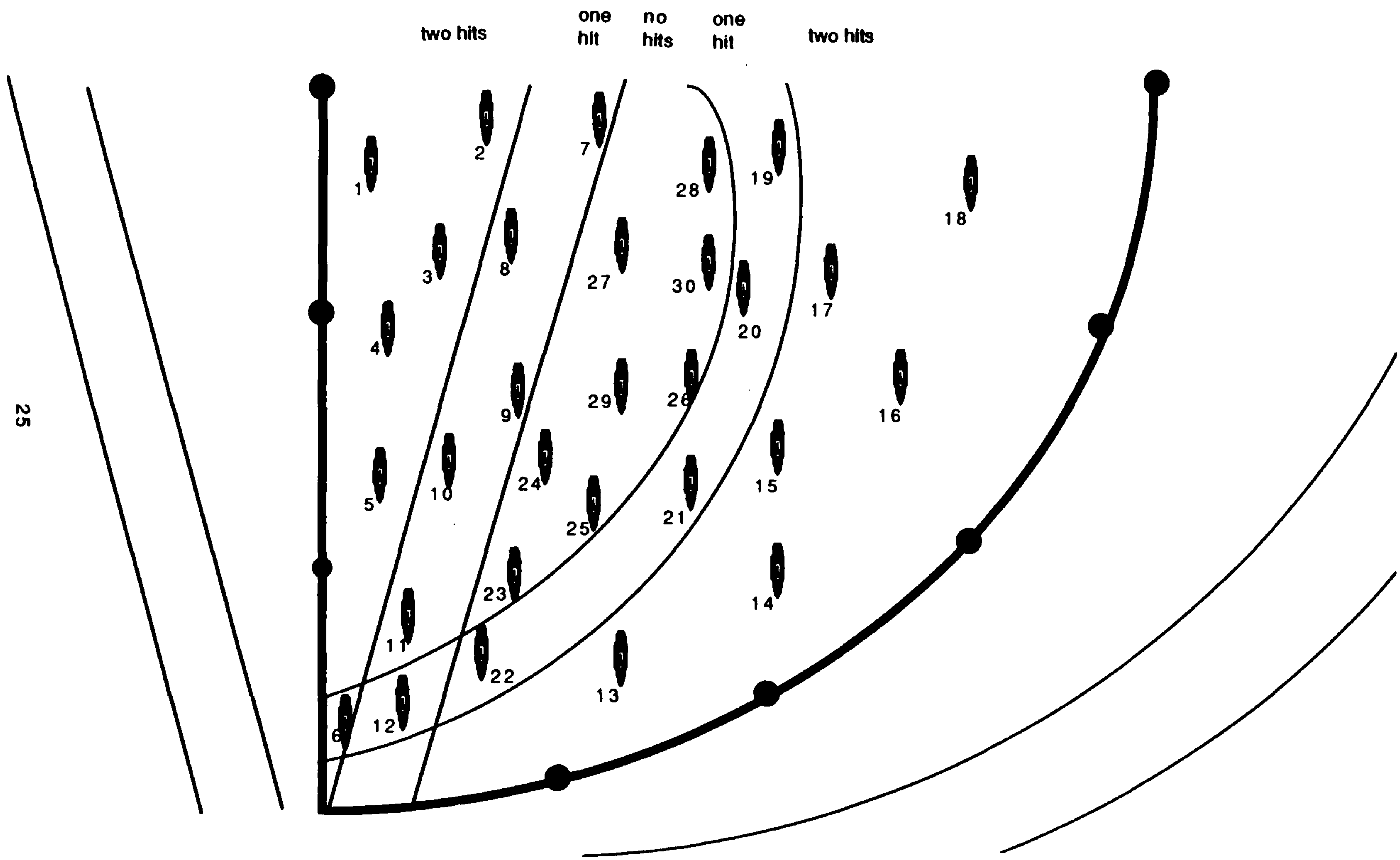


Figure 3-7: Ship locations and contours (Experiment 2).

3.3.3. Use of individual hit estimates in alternative evaluation

The memory structures discussed so far are useful for estimating the hits from individual ships. These estimates can be used to evaluate alternatives in an "eyeball and count" process, whereby subjects would quickly estimate the number of hits from each ship along each path, sum the hits along each path, and select an alternative by applying the decision rule taught in training.

3.3.4. Wholistic schemata for evaluating and ranking paths

Wholistic schemata enable the sum of ship hits along a path to be estimated from the overall pattern of ships. A schema of the kind described in the earlier ERA reports would be organized around a prototype pattern associated with a particular sum of individual ship hits. Its first layer would identify a set of features useful for estimating the total number of ship hits arising from similar patterns of ships. These features would represent the different dimensions along which one pattern could vary from another. The second layer would contain feature evaluation curves which relate the impact of pattern displacements of varying magnitudes along these different dimensions. The third layer, for actions and inferences, would not play a role in this wholly situation assessment task.

Figure 3-8 shows an example of the kind of schema that might support alternative selection for the problems presented to our subjects. This schema is organized around a baseline reference pattern, which serves as the organizing prototype. This pattern consists of three ships arranged in a triangular formation. Five possible schema features correspond to various types of displacements of the pattern. These features are:

1. Displacement of the pattern as a whole perpendicular to the path.
2. Displacement of the pattern as a whole parallel to the path.
3. Three individual ship schema of the type shown in figure 3-6. These three features show the use of embedded schemata, whereby "lower level" schemata become features of higher level ones.

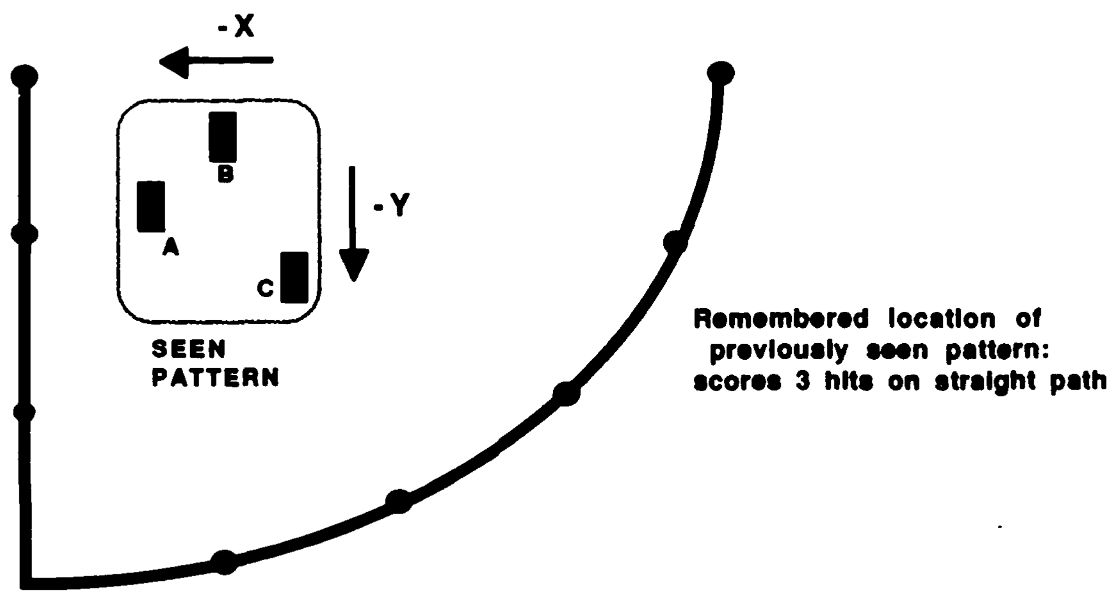
This schema could be used to estimate the number of hits from a new pattern of ships by comparing it with the baseline prototype pattern. The estimate would entail the following four steps:

1. The new pattern is recognized as being sufficiently similar to the baseline prototype to warrant use of the schema.
2. The number of ship hits by the baseline pattern is recalled.
3. Individual ship locations with respect to the overall pattern are evaluated, and adjustments to the baseline pattern score are calculated.
4. The two additional features, pattern horizontal displacement and pattern vertical displacement, are evaluated. These evaluation results are used to further adjust the number of ship hits estimated in the previous step.

Schema Features (used for identification):

X: horizontal displacement of pattern
Y: vertical displacement of pattern
A: individual ship schema*
B: individual ship schema*
C: individual ship schema*

*not shown below - see figure 3-6 for example



Feature evaluation data for features X and Y

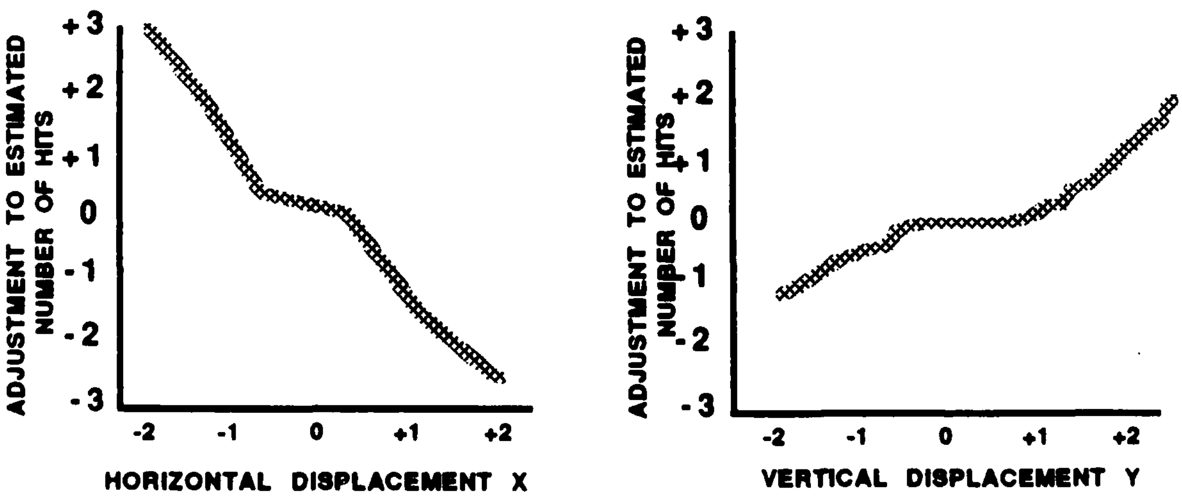


Figure 3-8: Wholistic schemata for path evaluation (Experiment 2).

4. EXPERIMENT 1

This section describes the first experiment investigating the contribution of memory reference structures to decision making. This task was described in section 3.2. Figure 3-1 is an example of the situation presented to subjects. As described in section 3.2, each subject was given detailed analytic procedures for calculating the number of hits his Battle Group would receive as it traversed the barrier along the straight or curved paths. The subjects were told to select the path that led to the fewest hits unless this number of hits was more than six. In that case, they were told to stay where they are.

4.1. Issues and design overview

This experiment focuses on two general issues: the type of memory structures that subjects might use to estimate the number of hits from each hostile ship; and the possible use of indicator/ counterindicator features to bypass the ship hit estimation when selecting an alternative.

Although subjects were trained to select the best alternative by projecting outcomes, they were encouraged by the design of the materials and by time pressure during the testing to adopt a decision strategy based on recognition of path quality. In particular, the following aspects of the design encouraged recognition based judgment and decision making.

1. During testing subjects are not provided with the ship movement and threat range measuring tools which were available during training.
2. It is not possible to make decisions based on simple visual comparisons of the straight and curved paths. The different shapes of the paths makes a direct comparison between the straight and curved path options impossible. In addition, the criteria for the stay option is a specific number of hits along the better path, a judgment not possible solely by comparing the paths.
3. The subjects were pressed for time. A careful measurement-based estimate took subjects about five minutes. During testing they were given only 10 seconds to rank the options (and an additional 10 seconds to record their rankings).
4. The procedure was tedious. The analytical outcome projection required a large number of routine measurements.

The following section describes the detailed methodology. Table 4-1 summarizes the test procedures designed to address the issues described in section 3.2.

4.2. Methods

4.2.1. Subjects

The subjects were twenty-five undergraduate students at George Mason University who received either course credit or payment for their participation. Five of the twenty-five subjects did not reach criterion during training. All twenty-five subjects participated in the test portion of the experiment. The responses of those who did not reach criterion were excluded from any analysis.

ISSUE		EXPERIMENT PROCEDURE	
1.	Subjects trained to calculate outcomes and use rules will develop memory reference structures which enable them to estimate ship hits quickly without measuring.	1.	Subjects rank options quickly without tools. The accuracy of these rankings is compared with accuracy expected were subjects guessing at random.
2.	Subjects' memory reference structures allow them to accurately estimate ship hits.	2.	Subjects estimate hits from each hostile ship. The accuracy of these estimates is computed.
3.	Subjects remember specific instances, but do not remember other information useful for estimating ship hits.	3.	Subjects evaluate hits from instances of previously seen ships and of ships that are displacements of the seen ships. The accuracy of hit estimates from previously seen and new ships are compared.
4.	Subjects use schemata for estimating hits from individual ships. Schemata are organized around the location of previously observed ships. They contain data for estimating changes in hits resulting from small changes in ship location.	4.	Subjects estimate hits from ships displaced from previously seen ships. The accuracy of hit estimates as a function of the direction and magnitude of the displacement is computed.
5.	Subjects abstract a mental map or set of contours that they use in estimating ship hits.	5.	Subjects outline and shade areas from where ships can score hits. The ship hit estimates predicted from their drawings are compared with their actual ship hit estimates.
6.	Subjects notice and/or use cues (indicator/ counterindicator features) that are paired with the alternatives and that identify the best alternative.	5.	Each of three experimenter-chosen cues is paired with one of the three options in all the training pictures and in the first half of the test The cue-alternative pairing is broken in the second set of test pictures. Accuracies of subjects' path ranking on two halves of test are compared. In debriefing, subjects are asked if they noticed anything that helped them in making their decisions in order to determine if they were aware of the cues.

Table 4-1. Issues and experimental procedures (Experiment 1).

4.2.2. Materials

Materials consisted of (1) path evaluation pictures that portrayed hostile barriers and alternative path options, (2) individual ship pictures that showed individual hostile ships and the path options, and (3) pictures which show the two path options, but do not contain any ships or submarine patrol areas.

The path evaluation pictures included twenty-four training pictures and twenty-four test pictures. Pictures were arranged in four sets of twelve each. One set was used for initial training, one set for training to criteria, and two sets were used in the test portion of the experiment. The path evaluation pictures and asnwer sheets used in training were hardcopy booklets. The path evaluation pictures used in parts I, II, and III of the testing.were slides projected for a specific length of time. Sample pictures are shown in Figure 3-1 and A-1, A-2, and A-3 in Apendix A.

All path evaluation pictures are similar in several respects. Each picture has the same path options (straight and curved) represented by the heavy dark lines. The dots along the paths represent the distance that the subjects' Battle Group could travel in one time unit. All pictures have exactly four enemy ships and four shaded areas representing areas where enemy submarines may be operating. The specific locations of the enemy ships and submarine areas vary between pictures and determine for each picture the rankings of the options: take the straight path; take the curved path; or stay.

In addition, every picture has exactly one of three indicator/ counterindicator features. The indicator/ counterindicator features are:

A single ship outside the curved path as shown in Figure A-1;

A pair of ships near the end of the straight path as shown in Figure A-2; and

Overlapping submarine areas as shown in Figure A-3.

In three of the sets of path evaluation pictures (initial training, training to criterion, and the first set of test pictures), the indicator/ counterindicator features reliably indicate the best option. In these three sets the best option for any picture having a single ship outside of the curved path is the straight path. Likewise, if a picture has a pair of ships near the end of the straight path, then the curved path is best. For any picture with overlapping submarine areas, the stay option is best.

In the fourth set of pictures the pairing of these potential features with a best option is broken. In this set, subjects using the indicator/ counterindicator features would never select the correct option.

Each set has two pictures with each of the following rankings:

	1st choice	2nd choice	3rd choice
1	straight path	curved path	stay
2	straight path	stay	curved path
3	curved path	straight path	stay
4	curved path	stay	straight path
5	stay	straight path	curved path
6	stay	curved path	straight path

Enemy ships were shown in 24 locations. Figure 4-1 shows the locations of each of the 24 ships. Within each set of pictures ships in each of the first 12 locations are shown three times and ships in each of the next 12 locations are shown once each.

The sets of pictures were designed to be of comparable difficulty. Difficulty in selecting the best option is believed to be inversely related to the difference in the number of hits between the first and second ranked options. The differences in the number of hits between these options were matched as closely as possible over the four sets. Table 4-2 shows the number of pictures in each set having each difference between the first two choice options. The set deemed slightly more difficult was chosen as the set to be used in the training to criterion. The set in which the potential features are inconsistent with the options had to be the second half of the test set. The other two sets were randomly assigned as initial training and as the first half of the test.

picture set	Differences in number of hits		
	0	1	2
Initial training	3	6	3
Train. to Crit.	2	10	-
Test (1-12)	3	6	3
Test (13-24)	3	7	2

Table 4-2: Number of pictures in each set with differences between first and second choice options of zero, one, or two hits on Battle Group.

There were five sets of single ship pictures (sets A, B, C, D, and E) with 12 pictures in each set. The ships in set A are in locations #1-12 and were seen many times by subjects in the training and testing. Ships in the pictures in sets B, C, D, and E are in locations displaced from these original 12 locations. Figure 4-2 shows the location of each of the original 12 ships and their

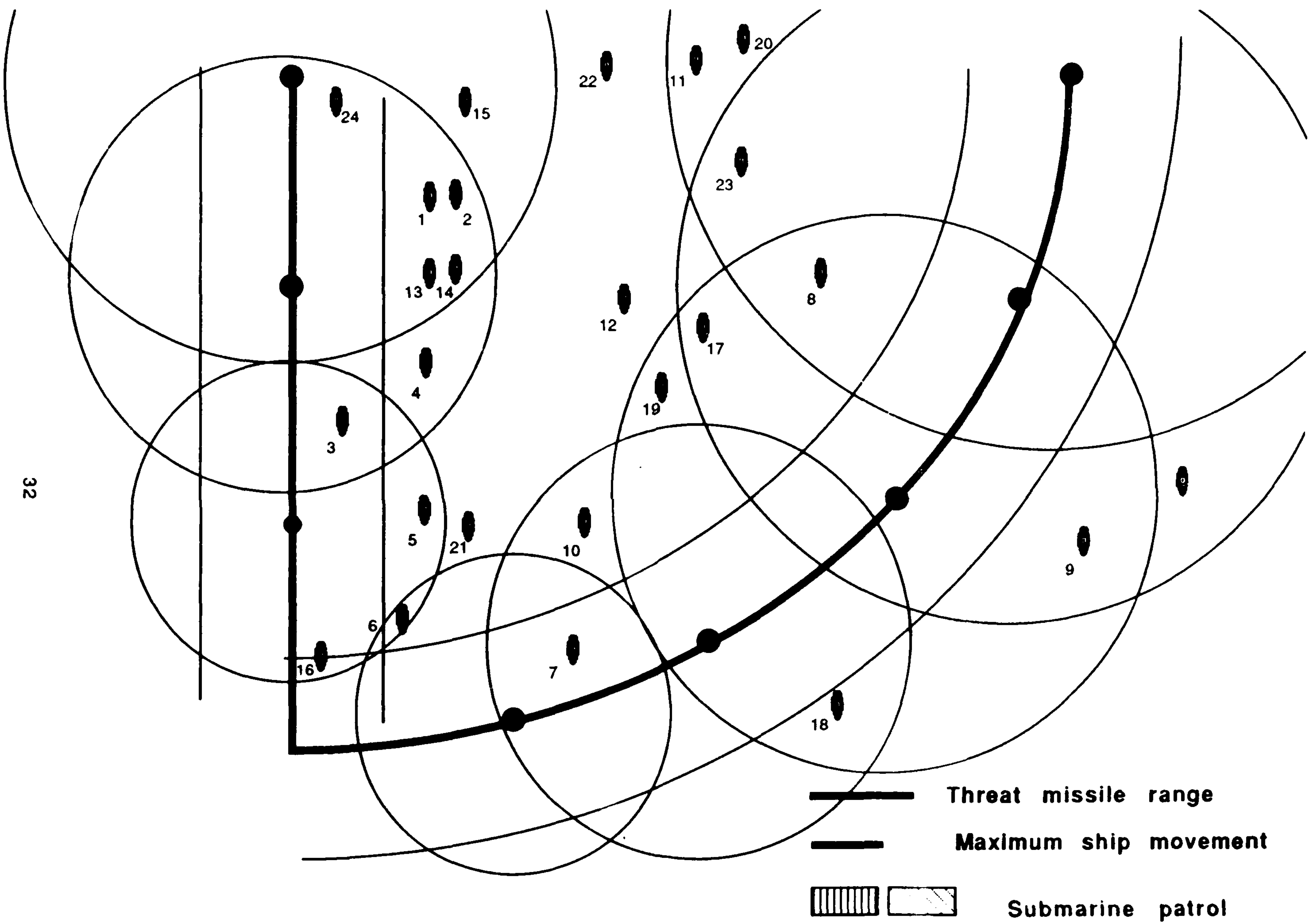


Figure 4-1: Ship locations and contours (Experiment 1)

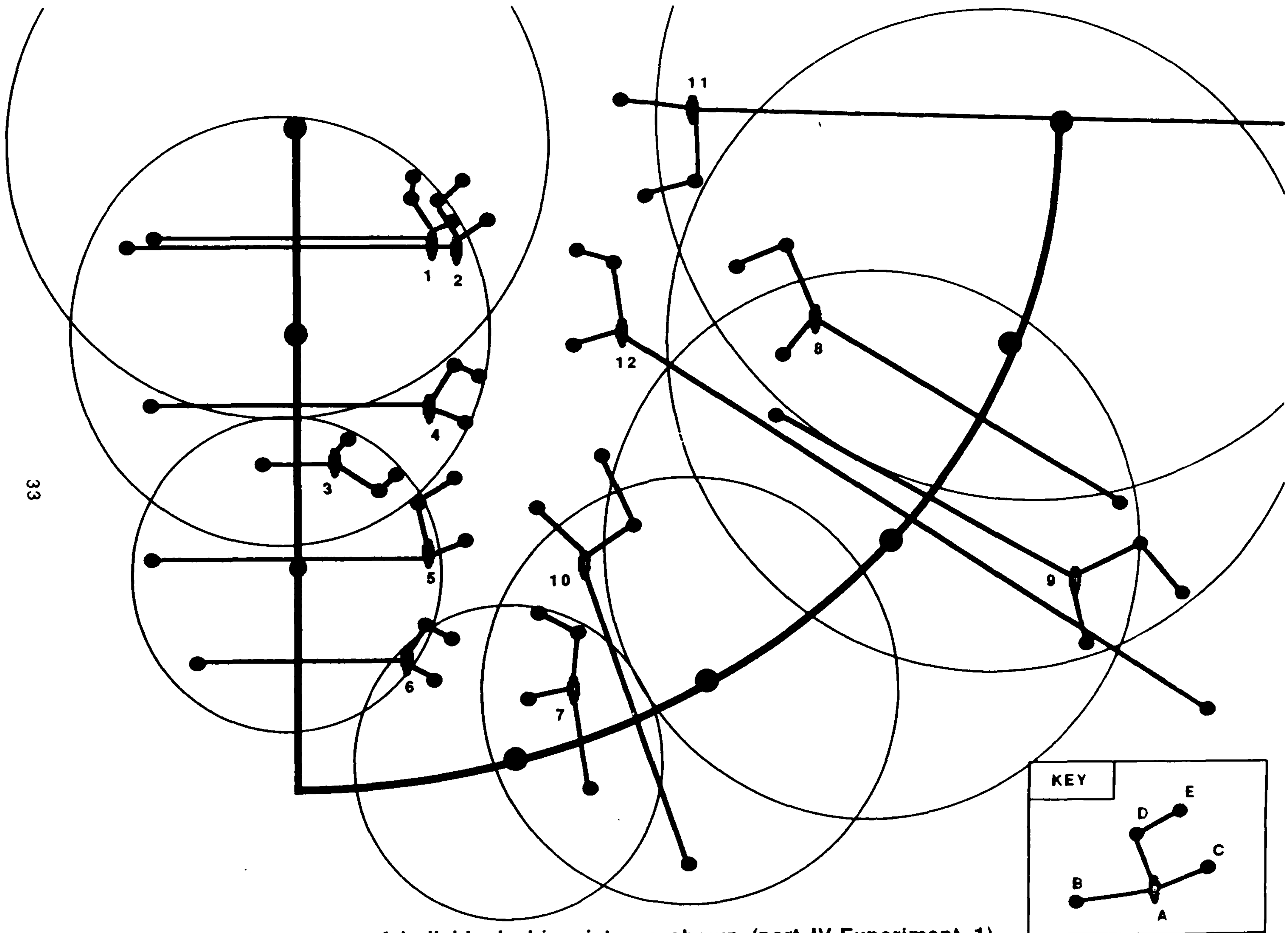


Figure 4-2: Composite of individual ship pictures shown (part IV-Experiment 1).

displacements. Ships in set B are reflections of the original 12 with respect to the paths with which they are associated. Ships in set C are displaced from the original location in a direction perpendicular to ship hit circles. Ships in set D are displaced in a direction parallel to the ship hit circles. Finally, ships in set E are displaced from ships in set D in a direction perpendicular to the ship hit circles.

The last type of material, used in part V of the experiment, showed only the straight and curved paths and did not display ships.

4.2.3. Procedure

Training procedure

Each subject was told that he was a commander of a Battle Group whose mission was to penetrate a barrier if possible. He was responsible for deciding whether his Battle Group should try to penetrate the barrier along the straight path, along the curved path, or not at all. In the last case, the Battle Group would stay at the "X" on the situation diagram. Subjects were told that one way to decide was based upon determining the number of hits that might be received from enemy ships and submarines. They were given complex procedures for determining the number of hits of each type for each path option. (These directions are summarized in section 3.2.) In addition, they were given 'tools', a cardboard threat range circle and a cardboard ruler marked in units of the distance that enemy ships travel per hour. Tools were used as an aid for computing the hits from enemy ships and submarines. Subjects were told that "there may be other ways to decide which path is best" and that as they became familiar with the pictures they might notice things that could be helpful in making their decisions. The procedures for calculating hits were purposefully complicated to motivate subjects to seek non-computational methods of alternative selection.

For each training picture, subjects were told to take a brief look at the picture and to record their guess of the ranking of the options. Following this guess subjects were asked to use the tools in order to actually measure and draw the ship movements and the submarine "center-of gravity" dots. For the first six pictures in the initial training packet, they then summed the hits for each path, and compared their picture with an answer sheet that contained the correct ship movements and submarine dots for that picture. They concluded by recording the correct rankings of the options for the picture. For the second six pictures in the initial training booklet, their "tools" were taken away. Following the quick initial guess subjects were asked to carefully **estimate** the hits from ships and submarine areas. They then summed their estimated hits for each path, compared their results with the answer sheets', and recorded the correct rankings. The answer sheets for the second six pictures in this set also showed the correct ship movements and submarine dots, as well as the number of hits from ships and submarines and the total number of hits for each path.

Subjects were then given a second set of twelve training pictures and trained to criterion. This training was similar to the previous training. Subjects looked at the pictures briefly and recorded their guesses of the ranking of the alternatives. Then they reviewed the correct answer on the answer sheet. The answer sheets for this part did **not** have the lines for the ship

movements drawn **nor** were the dots for the submarine areas drawn. The answer sheets did however have the number of hits from each ship and submarine and the total number of hits along each path. Subjects reached criterion if they correctly chose the first ranked option in at least nine of the twelve pictures.

Test procedure

The test portion of the experiment contained five parts.

In part I subjects ranked the options (straight, curved, and stay) for the 24 test pictures (sets 3 and 4). Each picture was projected for 10 seconds. Subjects then had 10 additional seconds to record their rankings. All of the pictures in set 3, in which the indicator/ counterindicator features reliably indicate the correct option, were shown before the pictures set 4, in which the indicator/ counterindicator features always indicated an incorrect option. Within each set, the order of presentation was randomized.

In part II of the testing, subjects were asked to rate each of the paths and the barrier (as a whole) on a scale of 1 to 10. The first 12 test pictures (set 3) from part I were randomized three times in this part of the test. The first time the set was shown, subjects rated how good the barrier would be at blocking the Battle Group along the straight path. The second time the set was shown, subjects rated how good the barrier would be at blocking the Battle Group along the curved path. The third time the set was shown, subjects rated how good the barrier would be at blocking the Battle Group overall. Each picture was projected for five seconds each time it was shown.

In part III of the testing, the same 12 test pictures were shown once again in randomized order. In this part, subjects rated two statements: (a.) "Enemy ships are near the path" and (b.) "Path is patrolled by enemy subs." The statements were rated for how characteristic each statement was of each path in each picture. Each picture was projected for 20 seconds during which time the subjects analyzed and recorded the four ratings .

Part IV of the testing required subjects to make decisions about receiving hits from enemy ships. Subjects were shown the five sets of individual ship pictures. Each set contained 12 pictures. Each picture was projected for seven seconds. Subjects were given an answer sheet for each picture. These answer sheets showed the paths with the dots where the Battle Group could be hit. Subjects were to circle the dot (or dots) to indicate where each shown enemy ship could hit the subjects' Battle Group.

Part V of the test provided subjects with diagrams of the straight and curved paths. Subjects were asked to shade and label the areas where enemy ships capable of scoring hits could be located. There was no time limit for this task.

4.3. Results and discussion

Data collected support the hypothesis that the subjects developed a memory aid that facilitated path evaluation. Furthermore, the data are consistent with that aid being a fuzzy schema for estimating ship hits. The data do not support the use of contour discriminators that

divide the task pictures into regions of zero, one, and two hits. There is strong evidence that the indicator/ counterindicator features played no role in alternative selection.

4.3.1. Memory in task performance

The subjects' ability to correctly rank the alternatives suggest that some kind of memory aid developed. Subjects are able to rank the options much better than guessing alone would allow. Were they only guessing, the subjects would have picked the right alternative on only eight of 24 pictures. In fact, the average number of pictures correctly assessed was 13.95 of the 24 presented. This number is significantly better than the number right that would be predicted from guessing, $t(19) = 10.635$, $p < .01$. Figure 4-3 shows how often subjects selected the correct alternative.

A more complete analysis of subjects' ability to rank options considers not only their ability to identify the best option, but also their ability to correctly rank all three options. Ranking the three options requires determining the better option for each of the three possible pairs: straight v. curved; straight v. stay; and curved v. stay. If subjects were only guessing, then their answers for each pair would be equally probable and they would, on the average, correctly pick the better option half of the time, thus scoring1.5 out of 3 possible points for each picture. The expected score for random option selection for the 24 pictures would be 36. The subjects' actual mean score ($X = 51.750$) is significantly different than the expected score for guessing (36); $t(19) = 11.990$, $p < .01$.

4.3.2. Schemata for individual ships

The subjects are developing data in memory to help them estimate hits. Figure 4-4 shows their accuracy for estimating hits for the ships seen in training. Their estimates are far more accurate than chance. Data from part IV also indicates that subjects' memory helps them estimate ship hits.

In part IV subjects were asked to identify the exact set of path hit points (the circles on the paths) that individual ships can hit. Subjects were tested on 60 ships of which 48 were in locations that had not been seen in training. Subjects performing at random would identify the correct set very infrequently. Those adopting a simple rule of assuming that a ship would always hit only the "nearest" path hit point would get approximately 21 correct (or 35%). Subjects actually got an average of 42.3 correct (or 71%).

The data in memory to support ship hit estimates includes more than just the number of hits from ships seen in training. It includes, in addition, data that enable them to estimate hits from ships at new locations. If subjects could use only their memory of the number of hits from previously seen ships, then they would estimate the hits from previously seen ships better than the hits from ships in new locations. In fact, subjects can estimate the number of hits from ships at some new locations as well as they can estimate the hits from previously seen ships. Table 4-3 summarizes the data from part IV of the test. It shows that subjects do equally well for previously seen ships, for new ships at locations which are mirror reflections of the previously seen ships, and for new ships that are the same distance from the path hit points as a previously seen ship.

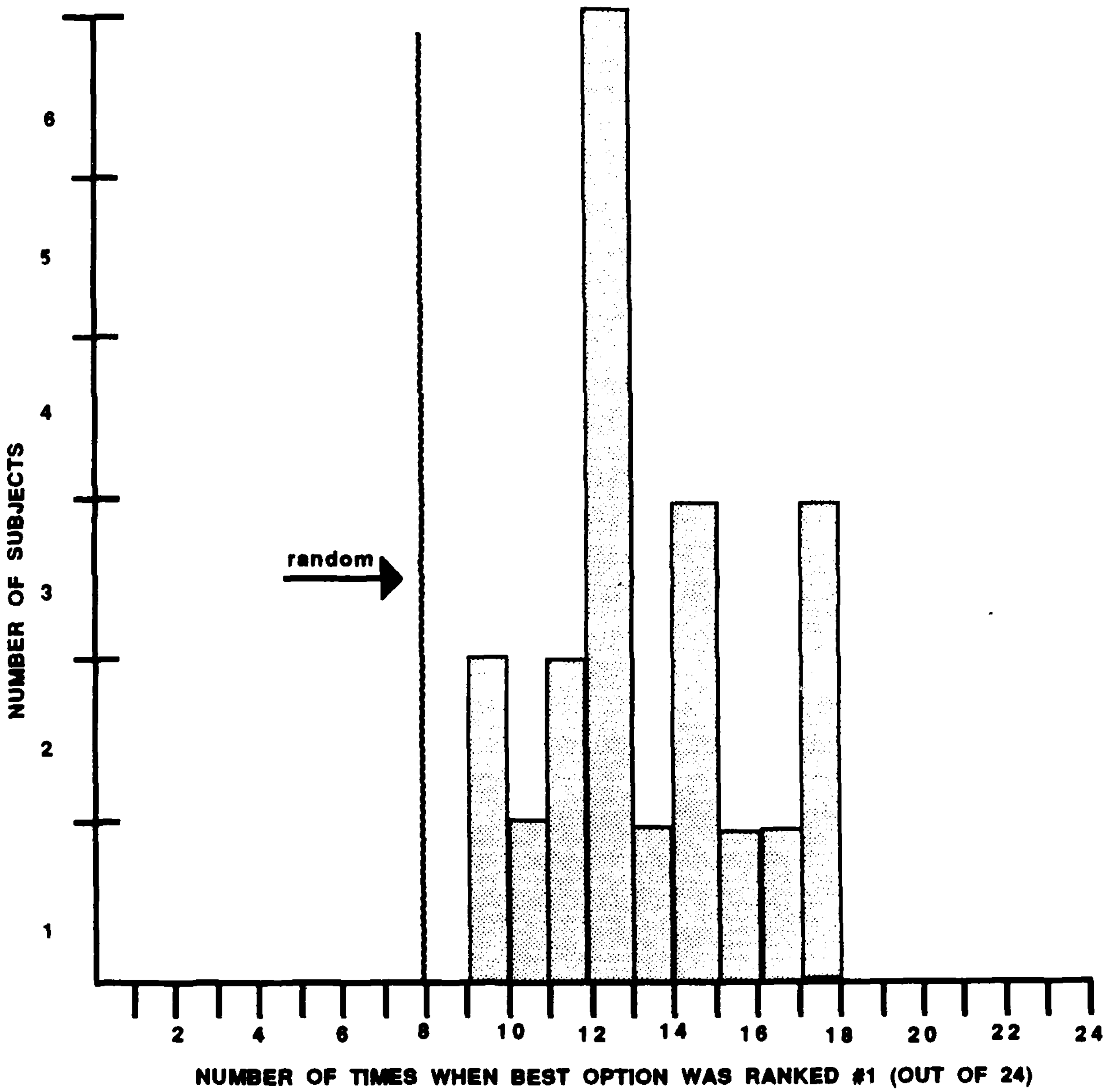


Figure 4-3: Accuracy of subjects' decisions (Experiment 1).

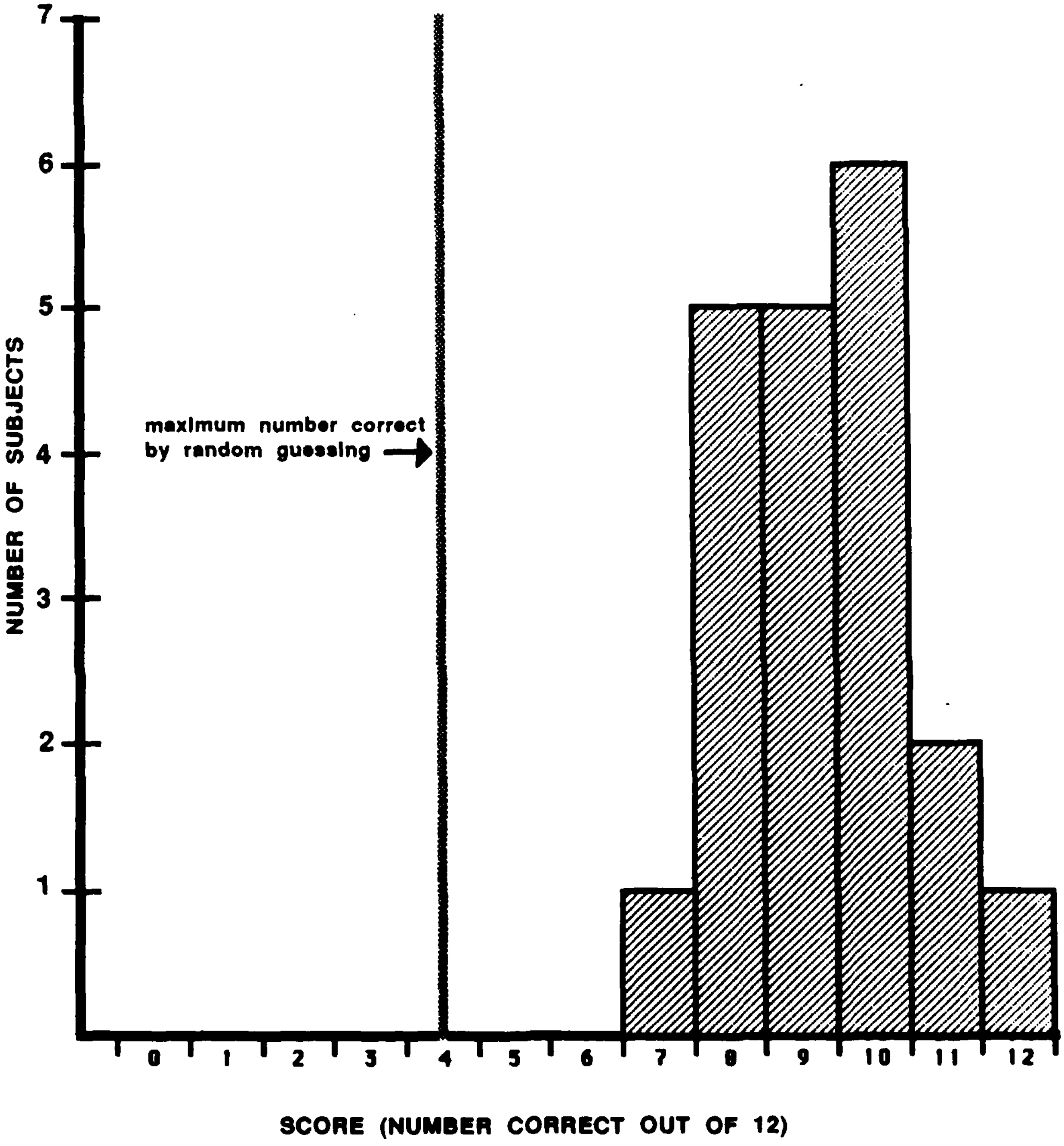


Figure 4-4: Accuracy of subjects' ship hit estimates for seen ships*

* set A, part IV, Experiment 1

A (SEEN SHIPS) NO DISPLACEMENT	B (REFLECTIONS) ANGULAR DISPLACEMENT	C (OUT FROM A) RADIAL DISPLACEMENT	D (PARALLEL) ANGULAR DISPLACEMENT	E (OUT FROM D) RADIAL DISPLACAEMENT
9.30	9.85	6.95	9.05	7.15

Table 4-3: Mean score for number of correct estimates of ship hits for different categories of ships (12 ships per category).

	B	C	D	E
A	t: -1.078 sig: .295	t: 6.092 sig: .000	t: 0.567 sig: .577	t: 6.750 sig: .000
B	—	t: 5.659 sig: .000	t: 1.752 sig: .096	t: 5.156 sig: .000
C	—	—	t: -4.228 sig: .000	t: -0.535 sig: .599
D	—	—	—	t: 4.790 sig: .000

Table 4-4: t-statistics and levels of significance between scores for sets A through E using paired t-tests with df=19 (part IV, Experiment 1).

There is no significant difference between ability to estimate hits from ships at these points. Subjects are significantly worse, however, at estimating hits from ships that are displaced radially from previously seen ships. Table 4-4 summarizes these data.

These data suggest that subjects' ability to estimate hits from ships in new locations is supported by schemata of the kind discussed in section 3.2.2 The schema hypothesis proposes that each schema contains the location and number of hits from a previously seen ship as well as feature data that enable subjects to evaluate the significance of ship displacements from the location of the previously seen ship. With these features they are able to estimate the number of hits from ships at new positions.

Subjects apparently understood the symmetry of the ship hit estimation and were able to use this understanding to estimate the hits from ships at new locations. They understood that angular changes in a ship's location with respect to a path hit point did not change that ship's ability to score a hit at that point. Even large physical displacements made no difference, so long as radial distance to the path hit point did not change. Quite small radial displacements, however, significantly affected their ability to estimate the hits from the displaced ship. A fuzzy schema with these two features, angular and radial displacement, was described in section 3.2.2. The data in Table 4-4 are consistent with that schema model.

Another kind of memory reference structure potentially able to support subjects' ship hit estimates are the discriminator contour curves that separate the task map into areas of zero, one, and two hits. These contours were described in section 3.2.2. If subjects had such contours in their memories, then they could estimate the number of hits by comparing the location of shown ships to the locations of the contours.The data collected from this experiment suggest that subjects do not use such contour curves.

In part V of the experiment subjects were given a paper with the printed Battle Group path alternatives. They were asked to draw on this paper the areas from which ships could obtain hits. Their drawings were highly inaccurate in defining the actual areas from which ships could obtain hits. Figure B-1 in appendix B is an example of a typical drawing. These drawings show that most subjects acquired some general understanding of the relationships between ship locations and ship hits. Fifteen of the subjects' drawings showed that ships further along the path could score hits from initial locations farther from the path. Six subjects drew circles, which is the mathematically correct shape of the contour. Although they seemed to understand some of the important factors affecting the ability of ships to score hits, subjects estimated very poorly the size of the areas from which ships could score hits. Subjects' ship hit estimates in part IV were consistent with their drawings in part V only 53% of the time (Figure 4-5).

The poor quality of these drawings argues against subjects using such contours as the basis of their ship hit estimates, but does not preclude such use. It is possible that people could be using contours for ship estimates and still be unable to draw them accurately.

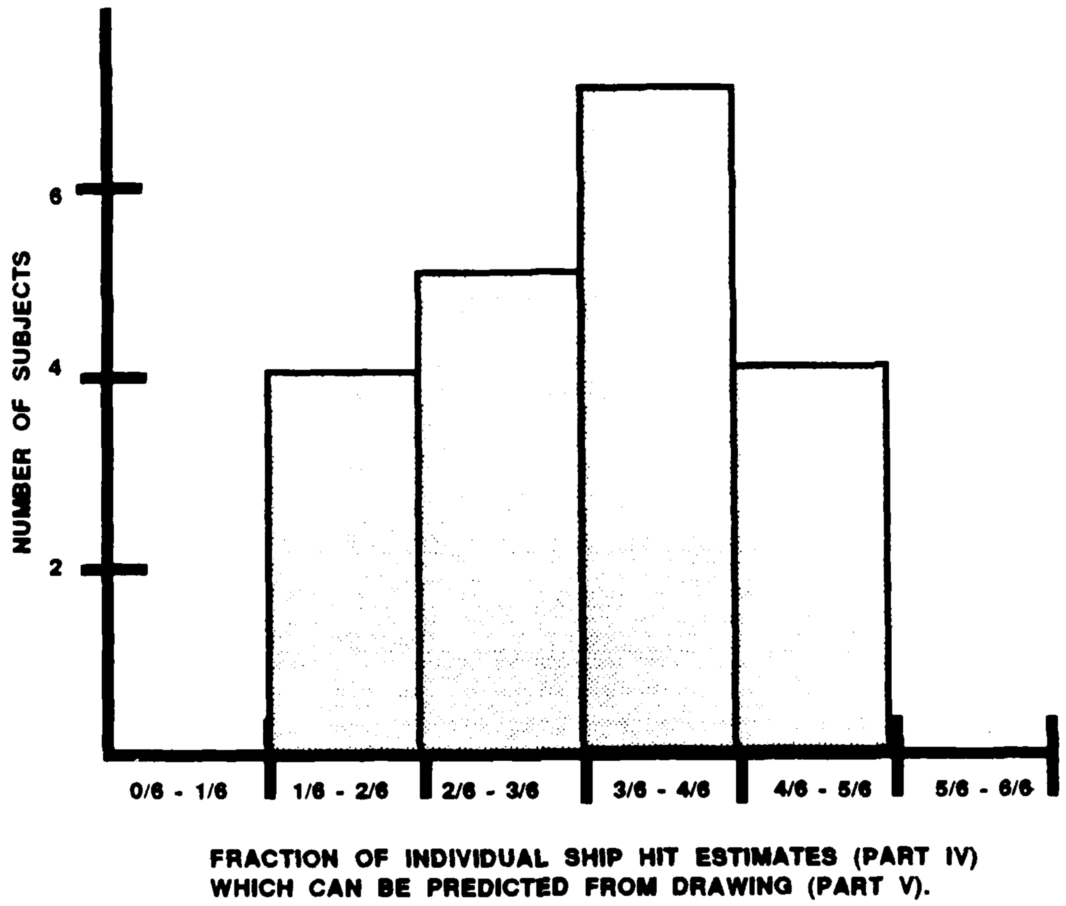


Figure 4-5: Inconsistency between ship hit estimates given and those inferred from drawing (Experiment 1).

4.3.3. Indicator/counter-indicators for alternative selection

A comparison of subjects' evaluations of paths in the first part of this experiment clearly shows that they did not use the indicator/ counterindicator features to help them identify the preferred option. The indicator/ counterindicator features were consistent with the first choice answer in the first 12 test pictures, but were inconsistent in the second 12 test pictures. If subjects were using the indicator/ counterindicator features, then they would select the correct option more often on the first twelve pictures than they would in the second twelve. They did not do so. Subjects did better on the second half of the test than on the first half. The number right on the first half of the test($X = 6.15$) is significantly worse than the number right on the second half of the test ($X = 7.80$); $t(19) = -3.885$, $p < .001$. Figure 4-6 shows these data.

Why did subjects do better on the second half of the test? Two explanations are offered. (1) Subjects may have become better at pacing themselves in the timed test situation and, therefore, tended to do better on later pictures. It is possible that this would have made a small difference in performance, but it is unlikely that it could account for this significant difference. (2) The pictures on the first half of the test may have been more difficult for the subjects than those on the second half of the test. This was explored further.

The materials were designed with the intent that both sets of pictures would be equally difficult. The same ships were shown the same number of times within each set and the differences between the options were equivalent between the sets. A closer examination of the materials, however, revealed that the path choices in the second set could be more difficult for subjects to rank.

Hits from some ship locations were generally less accurately estimated than hits from other locations. Some '2' hit ships are nearer to the '1' hit area than others. Some '1' hit ships are nearer to the '2' hit area and some are nearer to the '0' hit area. Ship ambiguity scores that reflect these estimation differences were computed for each of the 24 ships in the test pictures using the ship hit data from part IV. For example, a ship that was accurately rated '2' by 75% of the subjects would have a ship ambiguity score of 2.0 - .25. Path ambiguity scores were calculated from the ship ambiguity scores by summing the upper and lower estimates of hits from each ship along each path. A comparison of the path ambiguity scores (for the straight path, the curved path, and the '6' hit cut off for the stay option) in the two sets indicates that the first set of pictures are somewhat more difficult. There are 7 pictures in the first twelve in which the upper and lower bounds of ship hits along the path either overlap each other or overlap the stay option criteria of six hits. In the second twelve there are only 5 pictures having an ambiguity overlap. In addition the average size of the ambiguity overlap is larger in the first set. Thus, the first 12 pictures would be perceived as more difficult than the second twelve pictures .

In spite of these differences in the perception of picture difficulty, it is clear that subjects were not using the indicator/ counterindicator features in making their decisions. Furthermore, when debriefed, they indicated that they were not consciously aware of these cues.

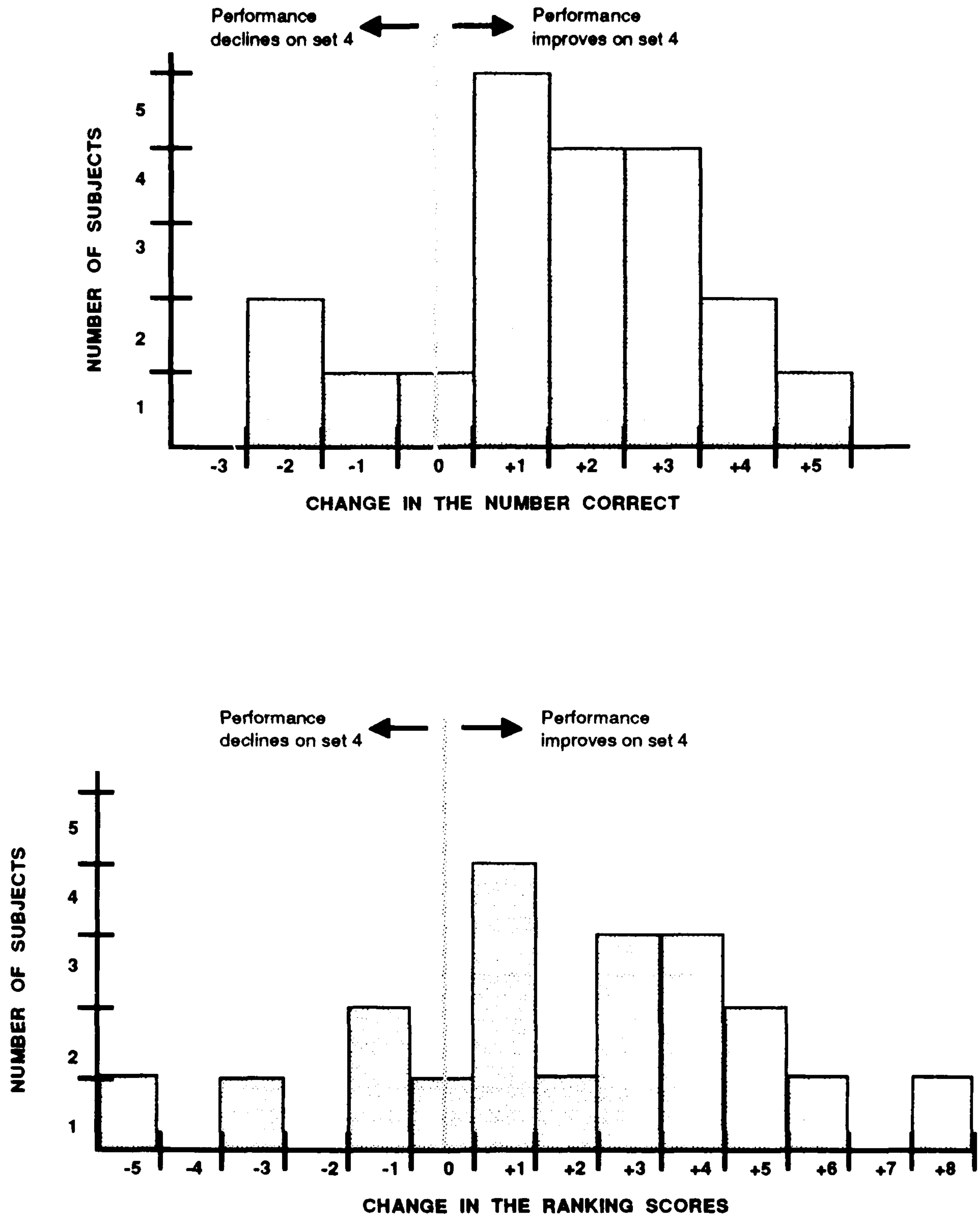


Figure 4-6: Comparisons of subjects' decision making abilities on set 3 and on set 4 (Experiment 1).

5. EXPERIMENT 2

The second experiment was designed to study more closely issues raised by the previous experiment. The decision task was described in section 3.3. Figure 3-5 is an example of the situation presented to subjects. As in the first experiment, subjects were asked to select the best option in response to this barrier: to traverse it along the straight path; to traverse it along the curved path, or to not traverse it, staying in front of the barrier.

5.1. Issues and design overview

Data from the first experiment suggest that people use schema-like memory structures for estimating ship hits, and clearly indicate that they do not use indicator/ counterindicator features for selecting alternatives without evaluating expected hits along the path. They also suggest that people do not base their hit estimates on contours separating the situation diagram into areas of zero, one, and two ship hits. Because the task in the first experiment was so complex and because the path quality depended on submarine patrol areas as well as on ship hits, it was not possible to investigate the connection between ship hit estimates and alternative selection. In addition, the task complexity may have inhibited subjects from forming "wholistic" path schemata for path evaluation.

In order to examine the connection between estimates of ship hits and the selection of a decision alternative and in order to encourage the formation of wholistic path schema, ERA simplified the previous task for this experiment. The barriers in this experiment contain only ships. There are no submarines. Ships can attack anywhere along the paths and do not need to change course to score a second hit. In addition, in order to test how the type of memory structure formed might be influenced by training, ERA trained subjects in three different ways.

Table 5-1 summarizes the test procedures designed to address the these issues.

5.2. Methods

5.2.1. Subjects

The subjects were undergraduate students at George Mason University who received either course credit or payment for their participation. Subjects were run in small groups of approximately four each. Each subject was assigned to one of three different training conditions: "measure", "curve", and "outcome". Eighty-three subjects participated in the study, 28 in the measure group; 23 in the curve group; and 32 in the outcome group. Twenty subjects reached criterion for each type of training.

ISSUE	EXPERIMENT PROCEDURE
1. Subjects trained to calculate outcomes and use rules will develop memory reference data to help them rank path alternatives.	1. Subjects are allowed very little time in which to estimate the number of hits from each ship and to rank the options. The accuracy and consistency of these rankings is computed.
2. Subjects' memories allow them to accurately estimate ship hits.	2. The accuracy and consistency of subjects' ship hit estimates are computed.
3. Subjects use schemata (similar to the type seen in task 1) for estimating hits from individual ships.	3. Subjects estimate hits from ships in several locations. Consistency of subject responses with schema predictions is evaluated.
4. Subjects abstract a mental map or set of contours that they use in making their decisions.	4. Subjects outline areas from where ships can score hits. The size and shape of these contours are examined. In addition ship hit estimates predicted from the drawn contour curves are compared with ship hit estimates actually given in parts IV and VII to determine whether they are significantly different. Some subjects are shown the ground truth contours during training. The accuracy of the ship estimates by this group is compared with the accuracy by other groups.
5. Subjects select the decision alternative by an "eyeball and count" process, in which subjects quickly estimate and sum individual ship hits.	5. Subjects estimate hits from individual ships. These estimates are used to predict their path rankings. The consistency of these predicted rankings with their actual rankings in parts I and VI is computed.
6. Subjects use a wholistic path schema to evaluate and estimate path quality.	6. Subjects provide ratings of path quality. These ratings are used to predict their path rankings. The consistency of these predicted rankings with their actual rankings in parts I and VI is computed.
7. Training mode does not affect subject performance because all subjects are trained to criterion.	7. Data are analyzed separately for each training group. Group differences reflect the influence of training on performance.

Table 5-1. Issues and experimental procedures (Experiment 2).

5.2.2. Materials

Materials consisted of three sets of 12 pictures each (initial training pictures, training to criteria pictures, and test pictures) and 30 single ship pictures. The two training sets were

packaged into training booklets with prepared answer sheets for each picture and a sheet on which subjects could record their answers. The test set and single ship pictures were made into slides for projection with a slide projector. A test booklet contained directions and pages on which subjects could record their responses. The pictures were identical for all groups, but the method for calculating the ship hits varied.

All pictures had the same thick lines indicating the straight and curved path options. The number of ships in the pictures (training and test) varied from 5 to 10. The sets of pictures (initial training, training to criteria, and test) were matched as closely as possible. Each set had the same ships shown the same number of times. Each set had the same pairs of path scores. The individual pictures differed only in the number and location of ships. No two pictures were alike. Every picture differed from the others by at least two ships.

The training pictures' answer sheets and supplemental materials were different for different training groups. During the initial training (pictures 1 - 12), the measure group had rulers that were used to measure and mark the ship movements. The measure group's answer sheets for both the initial training and the training to criteria showed the lines of measured ship movements. For the curve group the training pictures and answer sheets for both training sets contained the ground truth contour curves that separated the situation map into areas in which ships could score zero, one, or two hits. The outcome group's answer sheets for initial training and training to criteria marked the number of hits that ship could make next to each ship.

5.2.3. Procedure

Training procedure

There were three versions of training: measure, curve, and outcome. In the measure training, subjects were given rulers that showed how far a hostile ship can move in one time unit. Subjects were trained to measure the ship movements in order to determine ship hits for each path. In the curve group, the pictures contained the ground truth contour curves . Subjects could use these curves to determine the number of hits each ship could get for each path. In the outcome group, subjects were told to guess how many hits each hostile ship could score on each path. They then compared their guesses with the correct answers on answer sheets. In all cases, subjects were told to compute the total number of hits for each path and to then make a decision using the rule: "Chose the path with the least number of potential hits if that number is four or less. If that number is more than four, stay where you are."

After the initial training, subjects were provided with a second set of pictures and trained to criterion. These pictures were the same for all groups, but were followed by answer sheets that varied according to the training mode. Subjects recorded their rankings of the options on a score sheet and then compared their first choice with the correct first choice. The subjects scored their own papers. Subjects who got nine or more correct passed the training to criterion. Data from subjects who did not pass criterion was not analyzed.

The test portion of the experiment had seven parts. Pictures in the test set were randomized each time the set was shown. In part I subjects ranked the "straight," "curved," and

"stay" options for each picture in the test set. Each of these pictures were projected for 10 seconds. Subjects had an additional 10 seconds to record their rankings (straight path, curved path, or stay).

In part II subjects rated each path on a scale of 1 to 10 with respect to how good the path was at blocking the Battle Group. The set of test pictures was presented twice in part II. Each picture was projected for 5 seconds. In the first presentation (part IIA), subjects rated the straight path. In the second presentation(part IIB), subjects rated the curved path.

In part III subjects rated each of the paths on a scale of 1 to 10 with respect to a second statement: "Many ships near the (_____) path." Again, each set was presented twice with each picture shown for 5 seconds. In part IIIA, subjects rated the straight paths and, in part IIIB, subjects rated the curved paths.

In part IV the single ship pictures were projected for 8 seconds each. Subjects entered on the answer sheet their confidence that the shown ship could score '0', '1', or '2' hits.

In part V subjects were provided with paper showing only the curved and straight paths, and were asked to draw contours separating the areas from which ships could score zero, one, or two hits. There was no time limit for this part.

Part VI repeated part I (ranking the options) and part VII repeated part IV (recording the ship hits for the single ships).

5.3. Results and discussion

5.3.1. Memory in task performance

Subjects have developed data in memory that allow them to do this task. Subjects are able to rank the options much better than guessing alone would allow. The 12 test pictures were shown in parts I and VI (a total of 24 items). Figure 5-1A shows the distribution of the numbers correct for each of the three training groups. An item was considered correct if the option ranked first choice was the best option. The means for number correct are 17.00 (measure), 17.60(curve), and 16.15(outcome) which are all significantly different from the number correct predicted by guessing (8), $t(19) = 12.728, 15.884, 15.249$, respectively, $p < .01$. The scoring method used in the first experiment was again used to measure how well subjects could rank the three options. There were 3 points possible for each picture for a total of 72 points possible. Figure 5-1B shows the distribution of these scores for each training group. The means for the scores: 59.45(measure), 61.50(curve), and 57.40(outcome), are also significantly different from the score expected were subjects guessing at random (36), $t(19) = 19.301, 24.227, 20.942$, respectively, $p < .001$.

Training mode generally did not affect task performance. The differences in the number correct or in the ranking scores between the measured and the outcome groups are not significant, $t(38) = .959 (p = .344), 1.291 (p = .204)$, respectively. Similarly, the differences between the curve and measure groups are insignificant, $t(38) = .645 (p = .523), 1.275 (p = .210)$,

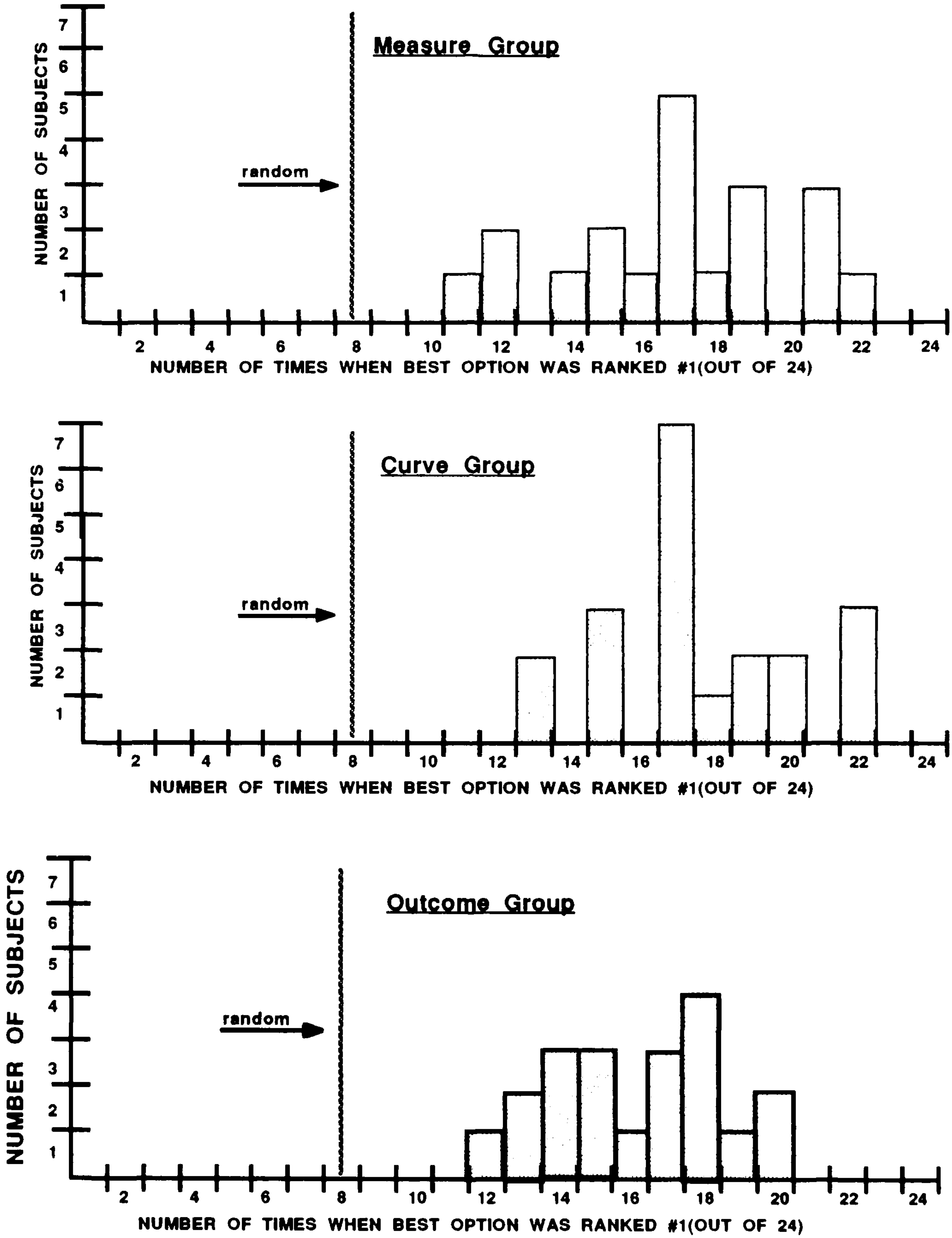


Figure 5-1A: Accuracy of subjects' decisions: the number correct (Experiment 2).

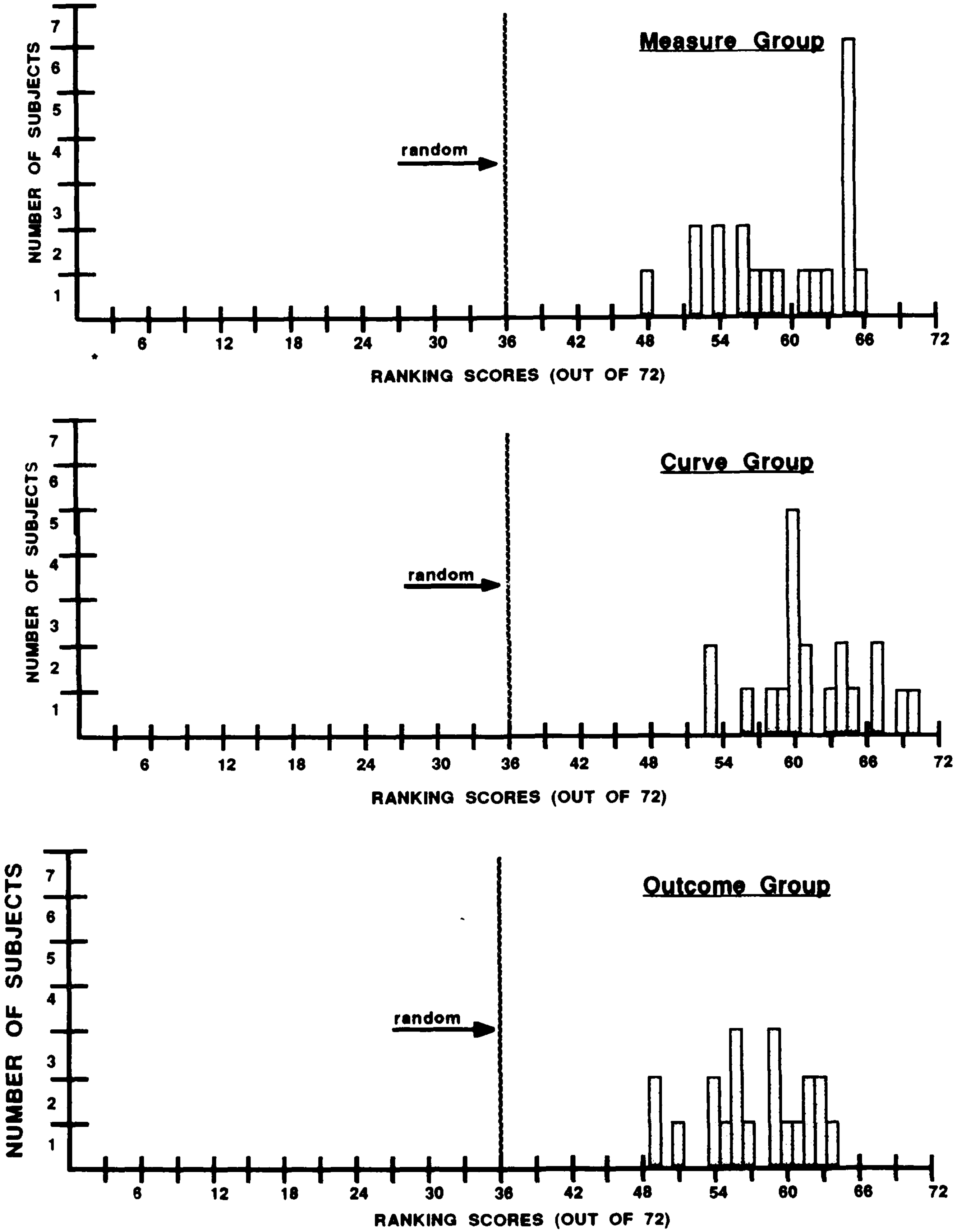


Figure 5-1B: Accuracy of subjects' decisions: ranking scores (Experiment 2).

respectively. For the curve and outcome groups the difference between the number correct is not significant, t(38) = 1.797(p = .08), but the difference between their ranking scores is significant, t(38) = 2.795, p = .008.

The test-retest consistency of subjects' rankings also supports the existence of memory reference structures. Figure 5-2 shows the consistency of rankings made in parts I and VI using the scoring method previously described (section 4.3.1).

Clearly, subjects can identify preferred options by looking briefly at the configuration of hostile ships. Since they do not have the tools to measure ship hits nor the time to carefully compute hits along paths, they must be using some other process to perform this task, presumably one based on memory.

5.3.2. Memory for ships

This process may employ memory aided ship hit estimates, for during training subjects acquired an ability to recognize previously seen ships and to remember the hits associated with them. This ability can be measured both in terms of the consistency of subjects' estimates, and also in in terms of their accuracy. Consistency is measured by the correlation between subjects test-retest responses. Accuracy is measured by how closely their estimates match the ground truth answers.

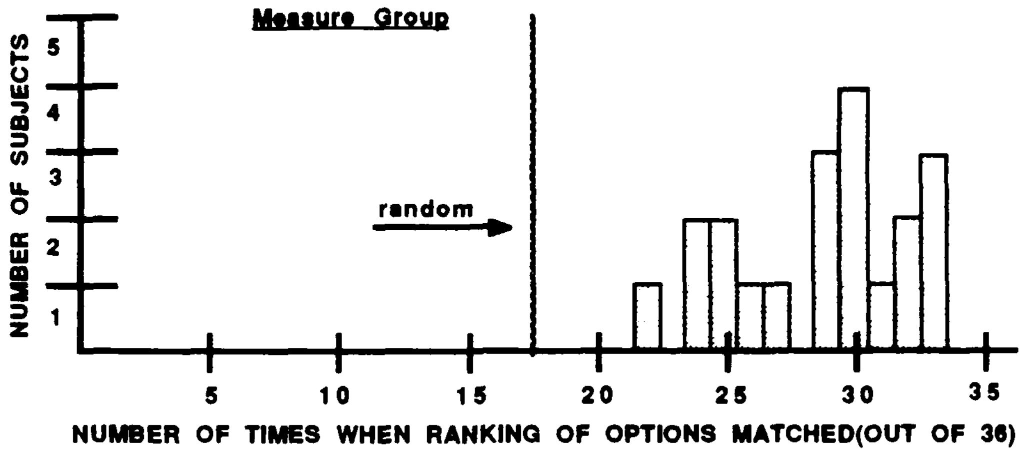
Subjects are very consistent in their estimates of ship hits. The coefficient of correlation between test-retest ship hit estimates in parts IV and VII was greater than .700 for most subjects. Very few had correlations below .500. Figure 5-3 shows the distribution of these correlation coefficients.

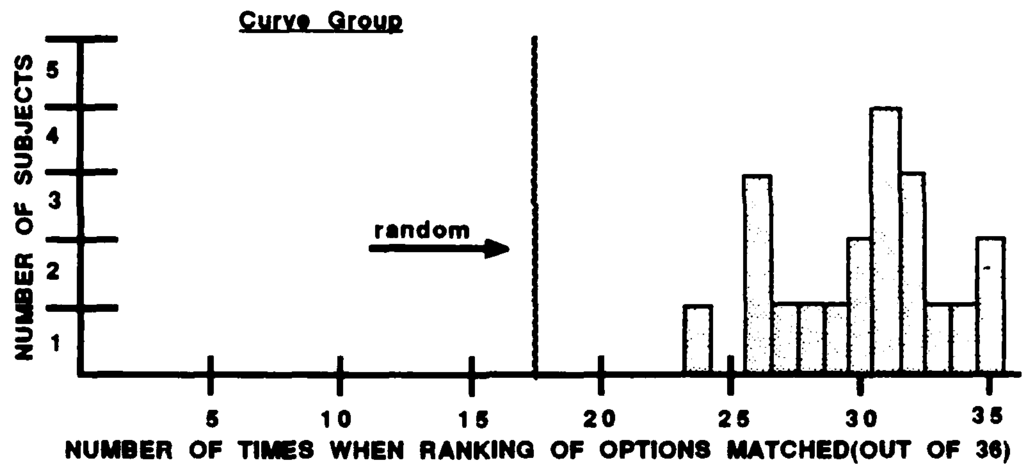
Subjects are also accurate in their ship estimates. Figure 5-4 show the mean estimate of hits for each ship shown.

5.3.3. Schemata for individual ships

Schemata for individual ships enable subjects to judge the effect of changes in ship location on hits from that ship. In this task, the schema data would indicate how the number of hits for a ship changes as its location changes either in a direction parallel to or perpendicular to the two ship paths.

These schema are reflected by the differences in subjects' ship hit estimates between pairs of ships that are either the same distance along the path but at different distances from the path, or are at the same distance from the path but are at different distances along the path. For example, ships #4 and #5 can both score 2 hits and are the same distance from the straight path, but ship #4 is further along the path than ship #5 and, therefore, has more time to reach the path. Subjects are generally more confident that ship #4 is capable of scoring 2 hits than they are that ship #5 is capable of scoring 2 hits (12 subjects were more confident of ship #4, 47 subjects were equally confident, and 1 subject was more confident of ship #5). The same relationship exists between ships #8 and #9 which are each capable of scoring 1 hit. Again, subjects were generally





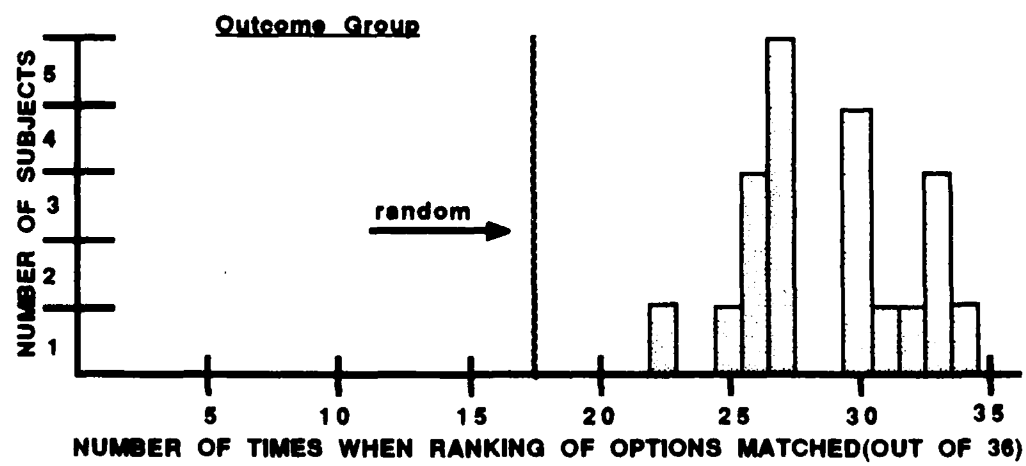


Figure 5-2: Consistency of subjects' decisions: rankings (parts I and VI - Experiment 2).

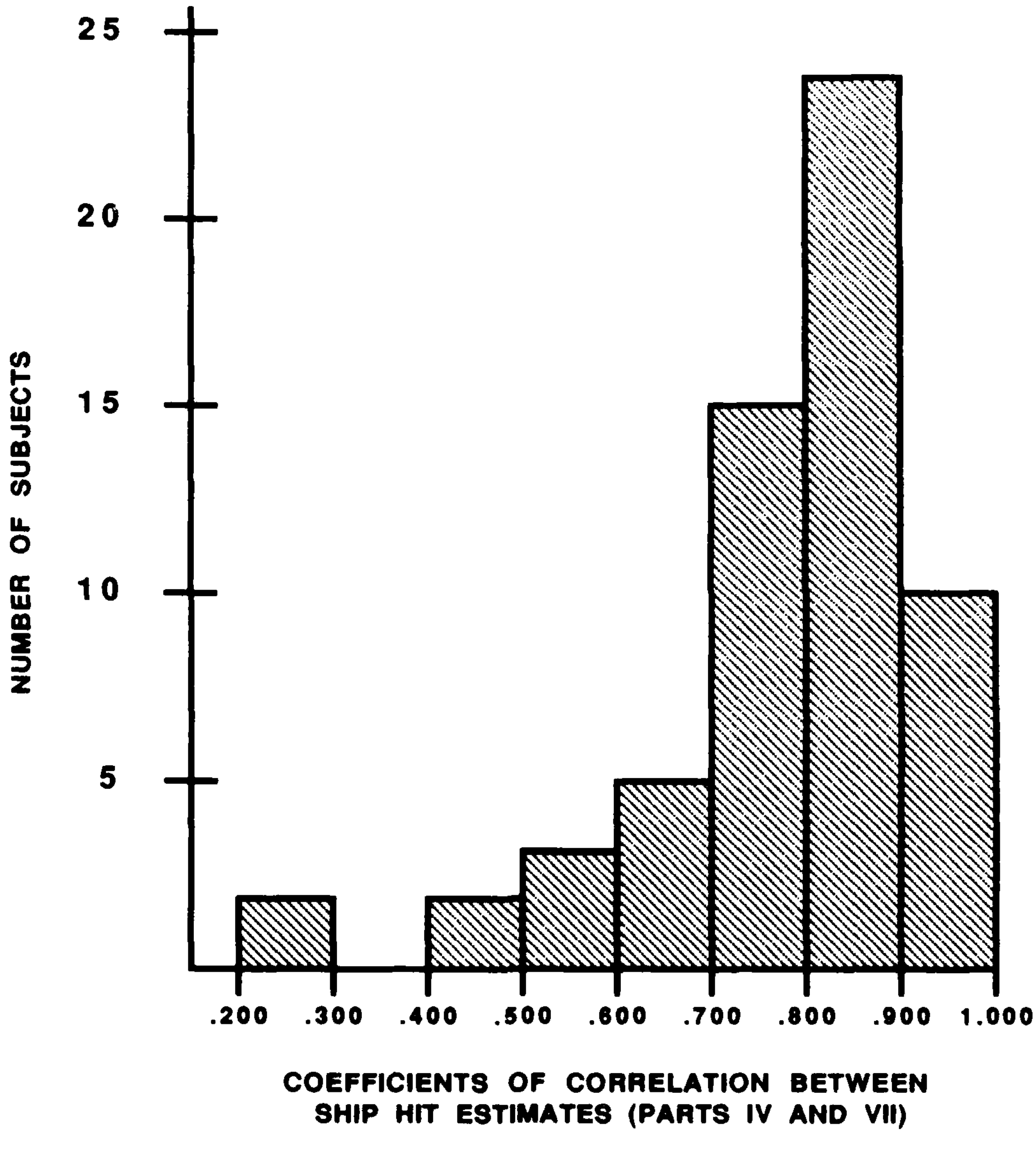


Figure 5-3: Consistency of subjects' ship hit estimates for seen ships (Experiment 2).

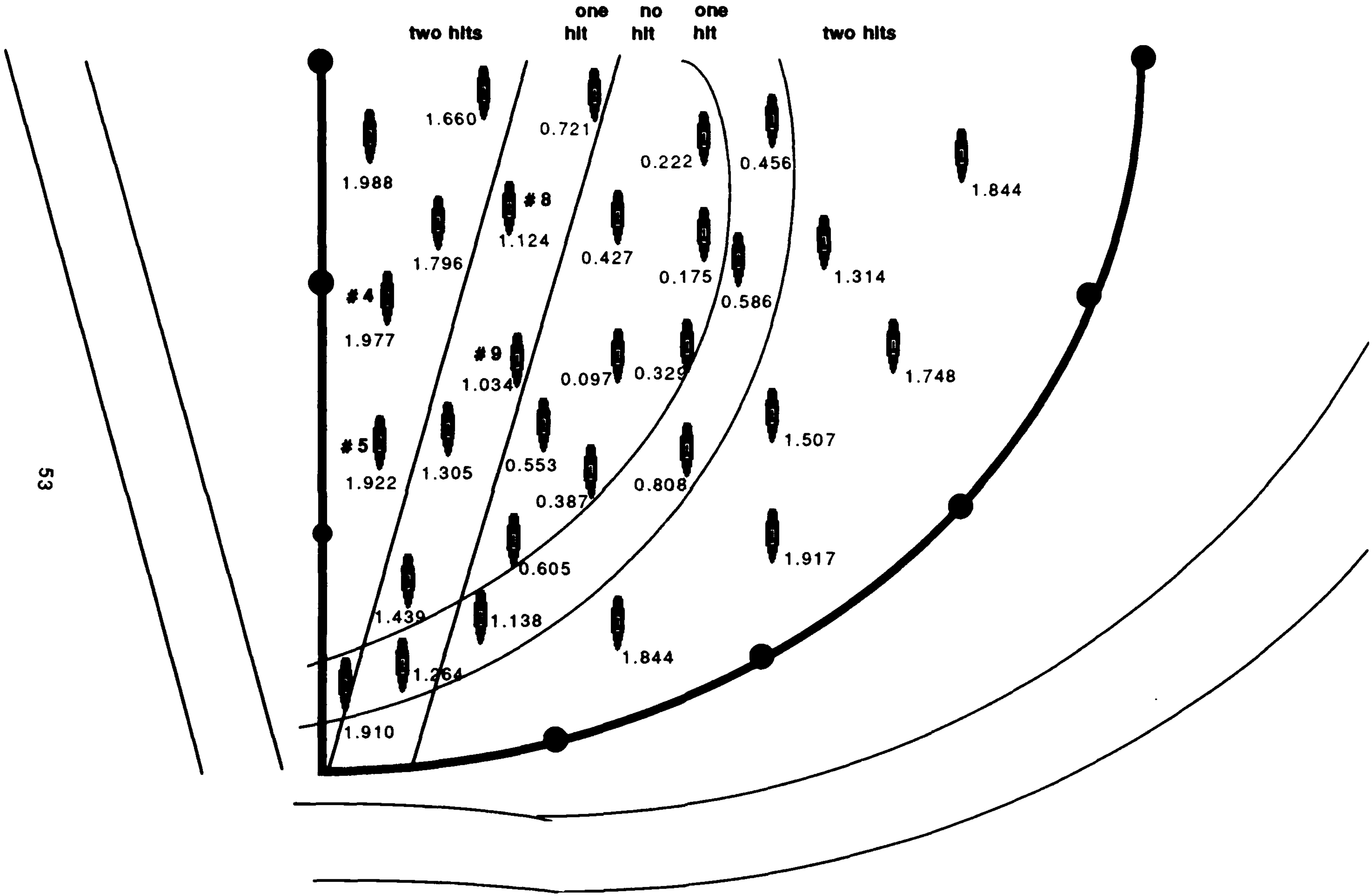


Figure 5-4: Accuracy of subjects' ship hit estimates (Experiment 2).

more confident of ship #8 than of ship #9 (30 subjects were more confident of ship #8, 11 subjects were equally confident, and 19 subjects were more confident of ship #9).

These findings support the schema structure for individual ships that was described in chapters 3 and 4.

5.3.4. Evidence against contour model

The contour model proposes that subjects have in memory reference curves that overlay the situation map, dividing it into areas from which ships can get no hits, one hit, or two hits. They use these contours to estimate hits from each ship by comparing the location of each ship with these contours. Ships outside the "0-1" contour would score no hits; those between the"0-1" contour and the "1-2" contour would score one hits; and those between the path and the "1-2" contour would score two hits. Ground truth contours are shown in Figures 3-7 and 5-4.

This experiment provides two kinds of evidence against the existence or use of such contours: the poor quality of contours drawn by the subjects, and the lack of impact that exposure to ground truth contours has on the accuracy of subject's ship hit estimates.

If subjects have these contours in their memories, then they may be able to draw them. If subjects are estimating ship hits by comparing the location of ships with the positions of the contours, then the ship hit estimates predicted from the contour locations should be consistent with the hit estimates provided directly by the subjects.

Figure B-2 in Appendix B shows a sample drawing. In general, the drawings show that subjects understand that the areas from which ships could score hits get wider further along the path and that the lines defining the '2' and '1' hit areas are parallel. Table 5-2 shows the number of drawings in each group of 20 subjects that were consistent with these ideas. The very high performance of the curve group is not surprising, for these subjects saw the ground truth contours during training.

Training group	**wider along path**	**parallel lines**
Measure group	17	11
Curve group	19	20
Outcome group	16	11

Table 5-2: Number of contour drawings with parallel contours between the one and two hit areas and with contours that diverge from path.

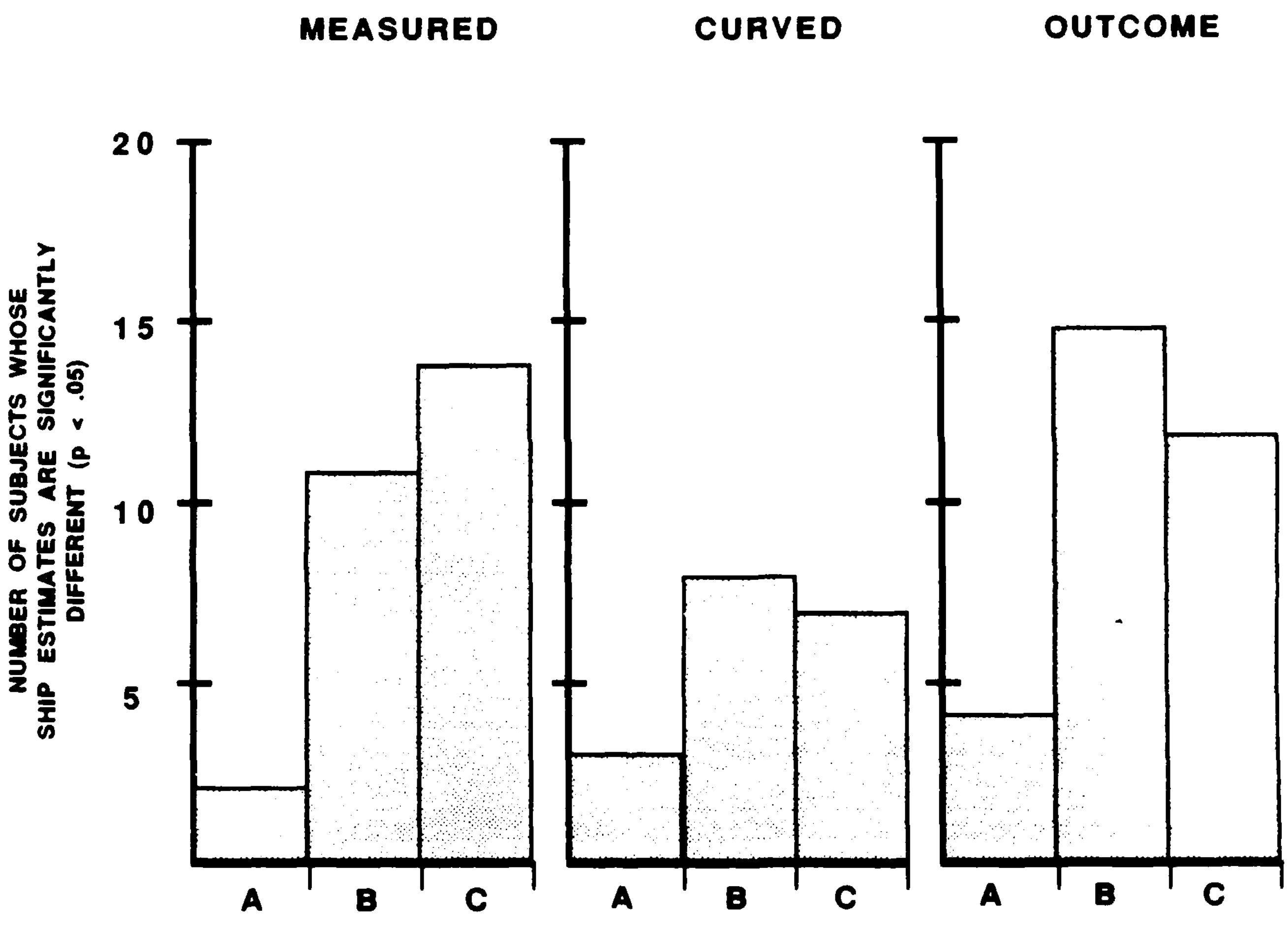
Subjects are not basing their ship hit estimates on the contours that they draw. The estimates that would be predicted from the drawn curves were obtained by superimposing the 30 ship locations on each subject's drawing to obtain ship hit scores for each ship. These inferred estimates were then compared with the estimates provided directly by the subjects. For each subject three paired t-tests were done: (1) between ship estimates given in parts IV and VII; (2) between ship estimates of part IV and the drawing-derived estimates; and (3) between ship estimates on part VII and the drawing-derived estimates. In most cases, there were no significant differences ($p < .05$) between the test-retest ship estimates given in parts IV and VII, but there were significant differences between the drawing-predicted estimates and each of the other estimates.

Figure 5-5 shows the number of cases in which the differences were significant for each training group. As illustrated, the drawings of the curve group, the group that saw the ground truth curves during training, were more consistent with their ship hit estimates than were either of the other group's drawings. However, even for the curve group, the consistency between the hits predicted from the drawings and the test or retest estimates was much less than the consistency between the test-retest estimates. It seems clear that subjects are not using the contours that they drew to estimate ship hits.

There is a possibility, however, that subjects have such contours in memory and are using them to estimate ship hits, but are unable to draw them accurately. We assume, for example, that people recognize their friends by comparing the faces of people they see with memory reference data describing the faces of their friends. Most people cannot draw these faces from memory very well. Their inability to do so does not preclude their having memory data for faces.

This difficulty was addressed by comparing the ship hit estimation ability of subjects trained on ground truth contours with those not trained on these contours. If subjects are using these contours to estimate ship hits, then subjects with more accurate contours would estimate ship hits more accurately than those with less accurate contours. Subjects in the "measure" or "outcome" training groups would need to abstract these contours from their measurements or observed outcomes. Those in the "curve" group saw the accurate contours during training. Therefore, it is likely that those in the measure and outcome groups would have less accurate contours than those in the curve group. If so, and if they are using these contours to estimate ship hits, then subjects in the measure and outcome groups should estimate ship hits less accurately than those in the contour group.

While the curve groups' drawings are indeed better, their ship hit estimates are not. Table 5-3 shows the average error in ship hit estimates for each group. The differences between the groups were not significant using unpaired t-tests ($t = 0.112$, sig = .911 between the measure and curve groups; $t = -0.576$, sig = .567 between the measure and outcome groups; and $t = -0.457$, sig = .649 between the curve and outcome groups.)



A	BETWEEN ESTIMATES PART IV AND ESTIMATES PART VII
B	BETWEEN ESTIMATES PART IV AND PREDICTIONS FROM DRAWINGS
C	BETWEEN ESTIMATES PART VII AND PREDICTIONS FROM DRAWINGS

Figure 5-5: Inconsistency between different ship hit estimates using paired t-tests (Experiment 1).

Measure group	Curve group	Outcome group
0.313	0.306	0.282

Table 5-3: Mean error in ship hit estimation.

5.3.5. Path evaluation from ship hits

Since subjects are able to estimate ship hits using schemata, they could be using these estimates to select among the straight, curve, and stay options. During testing subjects did not have the tools to calculate the potential hits, nor did they have the time to carefully estimate the potential hits. Yet, rather than abandon the calculations and projections learned in training, subjects reported in debriefings that they tried to make their decisions by quickly summing the ship hit estimates along each of the paths. Many subjects reported using this "eyeball and count" strategy.

The data are consistent with subjects using this strategy. Using the average of each subject's ship hit estimates from parts IV and VII, option rankings were predicted by summing over the hits from ships in each of the pictures. These predicted rankings were then compared with each of the subject's actual rankings (parts I and VI). The previously described scoring system was used to measure consistency between rankings. This system counted the number of straight v. curved, straight v. stay, and curved v. stay pairings that had the same order in the predicted and actual rankings. There were 3 points possible per picture. In addition, in order to provide a baseline, the consistency scores between the test and retest rankings were computed. The distribution of these consistency scores for each of the training group are shown in Figures 5-6, 5-7 and 5-8. The consistency of the predicted rankings with the actual test or retest rankings is very similar to the consistency between the test-retest rankings themselves. There were no significant differences ($p < .05$) between these three distributions for any group using paired t-tests. These data thus support the hypothesis that subjects were indeed basing their decisions on the quickly estimated ship hit sums.

There are many simple summing rules that subjects may have been using when evaluating the straight, curve, and stay options. While it is impossible to imagine all possible rules, it is possible to bound the complexity of the rule. For example, the following rule, which does not discriminate between ships able to score one or two hits, cannot account for subjects' performance. The rule is:

> Chose the path with the least number of ships near it, providing that the number is less than five. To determine if a ship is "near" a path, draw a line from the starting position to the midpoint between the ends of the two options. Ships to the left of the line are "near" the straight path. Those to the right of the line are "near" the curved path.

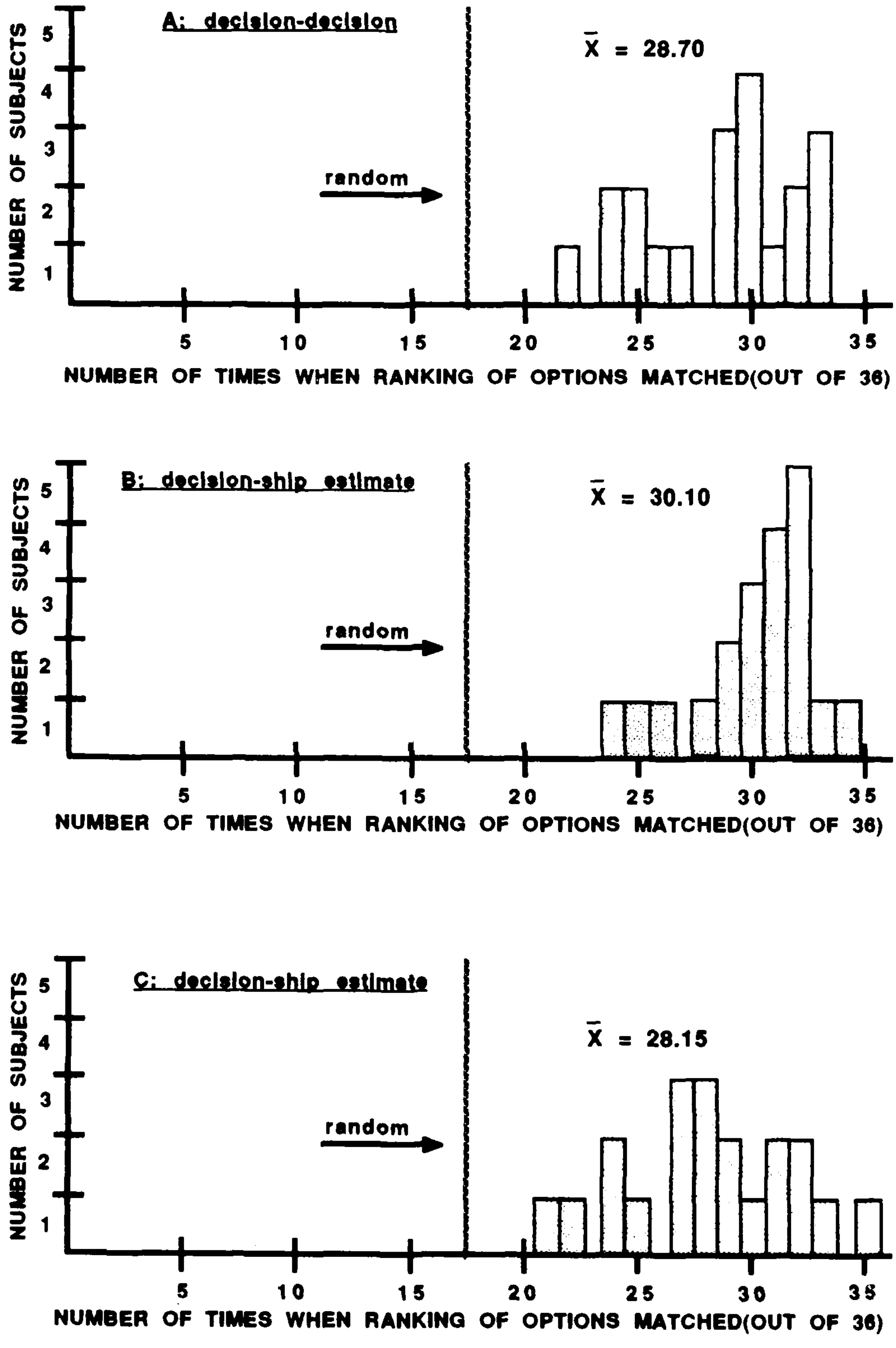


Figure 5-6: Consistency of decisions for the measure group:
(A) decisions(part I) with decisions(part VI);
(B) decisions(part I) with predicted decisions based on ship estimates; and
(C) decisions(part VI) with predicted decisions based on ship estimates.

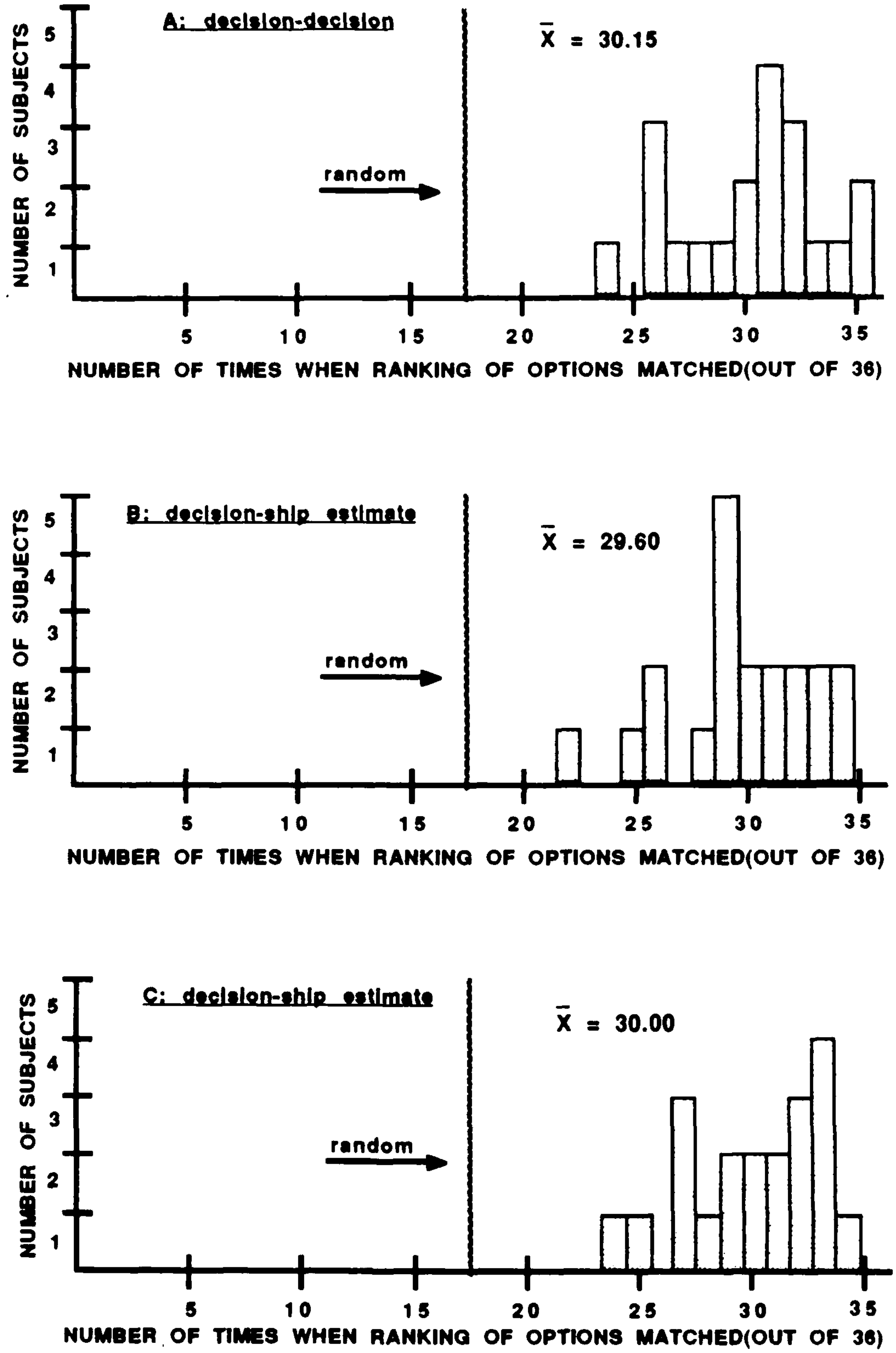


Figure 5-7: Consistency of decisions for the curve group:
(A) decisions(part I) with decisions(part VI);
(B) decisions(part I) with predicted decisions based on ship estimates; and
(C) decisions(part VI) with predicted decisions based on ship estimates.

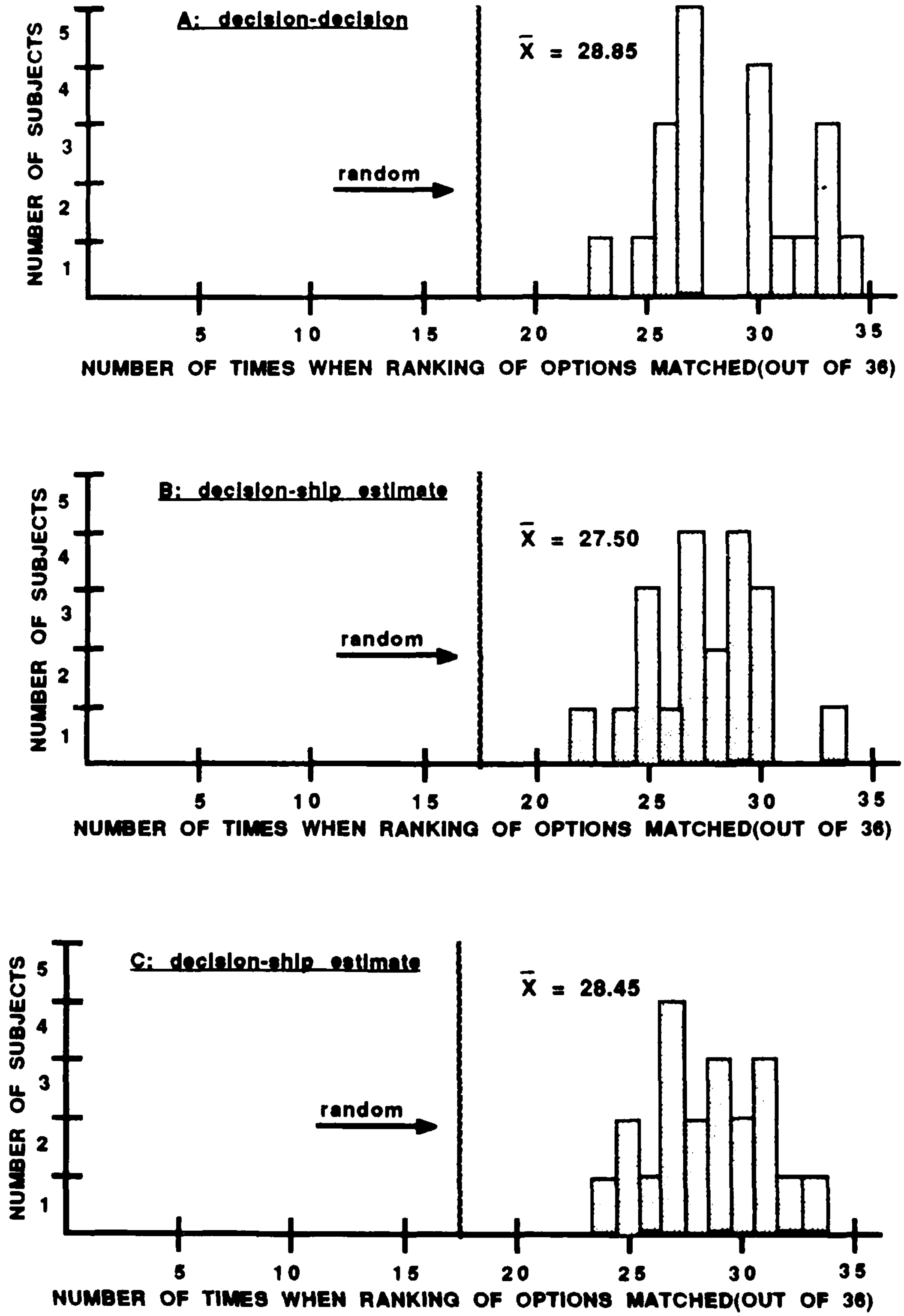


Figure 5-8: Consistency of decisions for the outcome group:
(A) decisions(part I) with decisions(part VI);
(B) decisions(part I) with predicted decisions based on ship estimates; and
(C) decisions(Part VI) with predicted decisions based on ship estimates.

Using this method, the expected score would be 48 and the expected number correct would be 11. The actual performance of subjects was better than what would be expected using this rule, $t(19) = 9.424$ (score), 8.485 (number correct) for the measured group; $t = 12.826$ (score), 10.920 (number correct) for the curve group; and $t = 9.199$ (score), 9.636 (number correct) for the outcome group, $p < .001$ for all groups. Even if subjects knew how to define "near" in a way that let them more accurately determine with which path(s) the ships should be associated, their expected score would be 53 and their expected number right would be 6 and both of these are significantly ($p < .001$) worse than actual subject performance. There doesn't seem to be any way of counting ships that allows subjects to perform as accurately as they did. Subjects must use their individual ship schema to estimate actual number of hits per ship in order to rank the options as accurately as they did.

The subjects' ability to estimate ship hits was sufficiently good so that in theory they could have ranked the options much more accurately than they did. The consistency scores of the rankings predicted from subject's ship hits with the ground truth rankings was 63.1 for the measure group, 64.6 for the curve group, and 63.2 for the outcome group (72 would be a perfect score), whereas the consistency scores of the actual rankings with ground truth was 59.45, 61.5, and 57.4 respectively for these groups. Time pressure is not likely to be the reason why subjects' actual rankings were less accurate than this theoretical maximum, for in an additional experiment five subjects given unlimited time to rank options showed the same pattern. Ship hit and summing variability, inherent in each estimation, is the most likely explanation. Such variability must be proposed to account for the consistency scores of 57.4, 60.3, and 57.7 between the test and retest rankings. Because similar consistency scores were observed between the rankings predicted from ship hit estimates and actual rankings, inherent estimation variability seems able to account for subjects failure to rank options as accurately as the theoretical accuracy imposed by their ship hit estimation accuracy.

5.3.6. Evidence against path schemata

It was hypothesized that with experience, subjects would develop "wholistic" schemata. These schemata would enable subjects to recognize an entire pattern of ships along a path, and to associate this pattern with a previously computed total number of hits. Subjects with such wholistic schemata would not need to "eyeball and count" Rather they would directly associate a pattern with a sum of hits. Wholistic schemata were discussed in section 3.3.4.

Although the "eyeball and count" model can account for subjects' rankings of options, it is possible that subjects also employed wholistic schemata when ranking options. Using wholistic schemata to rank options would likely entail less mental effort than the eyeball and count strategy. If subjects had such schemata, then they would likely prefer to use them, rather than eyeball and count, to rank options. Further, such wholistic schemata would also support subjects' qualititative assessments of path quality.

Subjects' qualitative path assessments provide some evidence that they did not use such schemata. In parts II and III of the experiment, subjects were required to rate the paths. In part II they rated paths according to "how good the path was at blocking the Battle Group." In part III of the experiment, subjects were required to rate how consistent each statement "Many ships are near the straight(curved) path." is with each path in each picture. If subjects abstracted wholistic schemata and were using them to assess path quality and also to rank options, then the ratings given in part II and III should be consistent with and correlate with the decisions they made in parts I and VI.

Although it is impossible to predict the order of the stay option with respect to the straight and curved options from these data, it is possible to predict the order of the straight and curve options (except when the curves are given the same ratings). For each subject, the order of the rankings for the straight and curve option was compared with the order predicted by the qualitative path rankings of part II and with the order predicted by the ship hit estimates. Table 5-4 summarizes the number of times these two different types of predictions were consistent with the actual path rankings. When the order of the rankings predicted by ship estimates differs from the order predicted by path assessments, then decisions are more consistent with ship estimates than with path assessments made in part II.

training group	ranking predicted by ship estimate only	ranking predicted by path assessment only	total number of cases
measure group	91	13	104
curve group	40	20	60
outcome group	69	37	106

Table 5-4: Comparison of decision consistency with ship hit estimates and path assessments .

Table 5-5 summarizes these data when the rankings are projected from the qualitative assessments of part III. This table shows the same pattern of table 5-4: subjects decisions are more consistent with their estimates of ship hits than with their qualitative path assessments.

Although these data do not completely preclude the existence of wholistic path schemata, they surely do not support them either. It seems likely that in this experiment such schemata did not form. It is possible that with enough experience, people would develop these schemata. There are several reasons why they did not form in these experiments, however.

First, during training there was no reinforcement of patterns. The ship locations are repeated, but no two pictures have the same combination of ships. Because the pictures are so varied, it would be very difficult for subjects to remember previously seen patterns.

training group	ranking predicted by ship estimate only	ranking predicted by feature statement only	total number of cases
measure group	61	33	94
curve group	30	24	54
outcome group	43	27	70

Table 5-5 Comparison of decision consistency with ship hit estimates and feature statements.

Second, there may be a tendency for people to anchor on a particular training method. Subjects are unable or unwilling to completely abandon the outcome calculation rule in favor of a feature or wholistic approach. Faced with time pressure that prevented them from using the exact method taught in training, they chose to approximate that method rather than switch to an entirely different method.

Third, the differences between the options in the training and test pictures are small. Therefore, the subjects may have judged that any wholistic schemata being formed were inadequate to select among the alternatives, and therefore the selection should be based on the "eyeball and count" strategy.

5.3.7. Effects of training method

The three different training modes, "measure," "curve," and "outcome," were selected to test different hypotheses concerning the use of schemata and other memory models. It was conjectured that:

1: The contour group would develop the best mental contours, and would be best at ship hit estimates if these contours are used for that purpose. In addition, subjects in this group would most easily see patterns of ships, and would be most likely to develop wholistic schemata.

2. The measure group would pay the most attention to individual ships. Because subjects in this group are given a rule or guidelines for determining ship hits, they should have the best understanding of the factors important in estimating ship hits. It was anticipated that they would have the best ship hit schemata.

3. The outcome group would have neither the contour curves nor the measurement rules to guide them. This group was expected to perform less well than the others.

The different training conditions did help to discriminate among the different memory models. The curve group did not estimate ship hits better than did the measure group, indicating that mental contours separating the task map into areas of zero, one, and two hits are unlikely to be used in estimating ship hits. None of the groups seem to have developed wholistic schemata. As the data in Tables 5-4 and 5-5 show, it is unclear that the curve group showed more evidence for these schemata than the other groups

Differences between training groups in performance during the test parts of the experiments were generally not significant. This is not because all training methods were equally effective, but rather because subjects trained to criterion. Performance differences were minimized because the only data analyzed was for subjects who reached criterion.

While it seems that different training methods do not cause different mental structures for this task, different methods of training do influence the rate at which formation for these structures. The most efficient training method was the curve method. Only 23 subjects were run to have 20 reach criterion. The second most efficient training method was the measuring method in which 28 subjects had to be run. The least efficient training method was the outcome method in which 32 subjects had to be run.

6. GENERAL DISCUSSION

The two experiments described in this report examined how memory interacts with outcome projection in decision making. In both decision tasks subjects were taught analytical procedures for identifying the best decision alternative. These procedures were complex, requiring several minutes to use. It was expected that with experience subjects would develop reference data in memory that would enable them to make good decisions when conditions would not allow them to use the analytical methods. During testing subjects were given only a few seconds to select the best alternative, a time much too brief to use the precise analytical procedures.

6.1. Relationship between experiments

The two experiments complemented each other. While concerned with the same overall issues, they focused on different detailed aspects of the use in memory in these decision making tasks. Table 6-1 summarizes the focus of the two experiments.

Issue	Experiment 1	Experiment 2
Use of memory in task	+	+
Fuzzy set schema for ships	++	+
Contours dividing areas of 0, 1, and 2 ship hits	+	++
Indicator/ counterindicator features	+	-
Eyeball and count alternative selection	-	++
Wholistic path schemata	-	+

Table 6-1. Issues addressed by Experiments 1 and 2.
Symbol legend: ++ investigated in depth; + addressed; - did not address.

6.2. Summary of results

Figure 6-1 summarizes different hypotheses concerning the use of memory in selecting the best action for the decision tasks in these experiments. Memory could contribute to two different parts

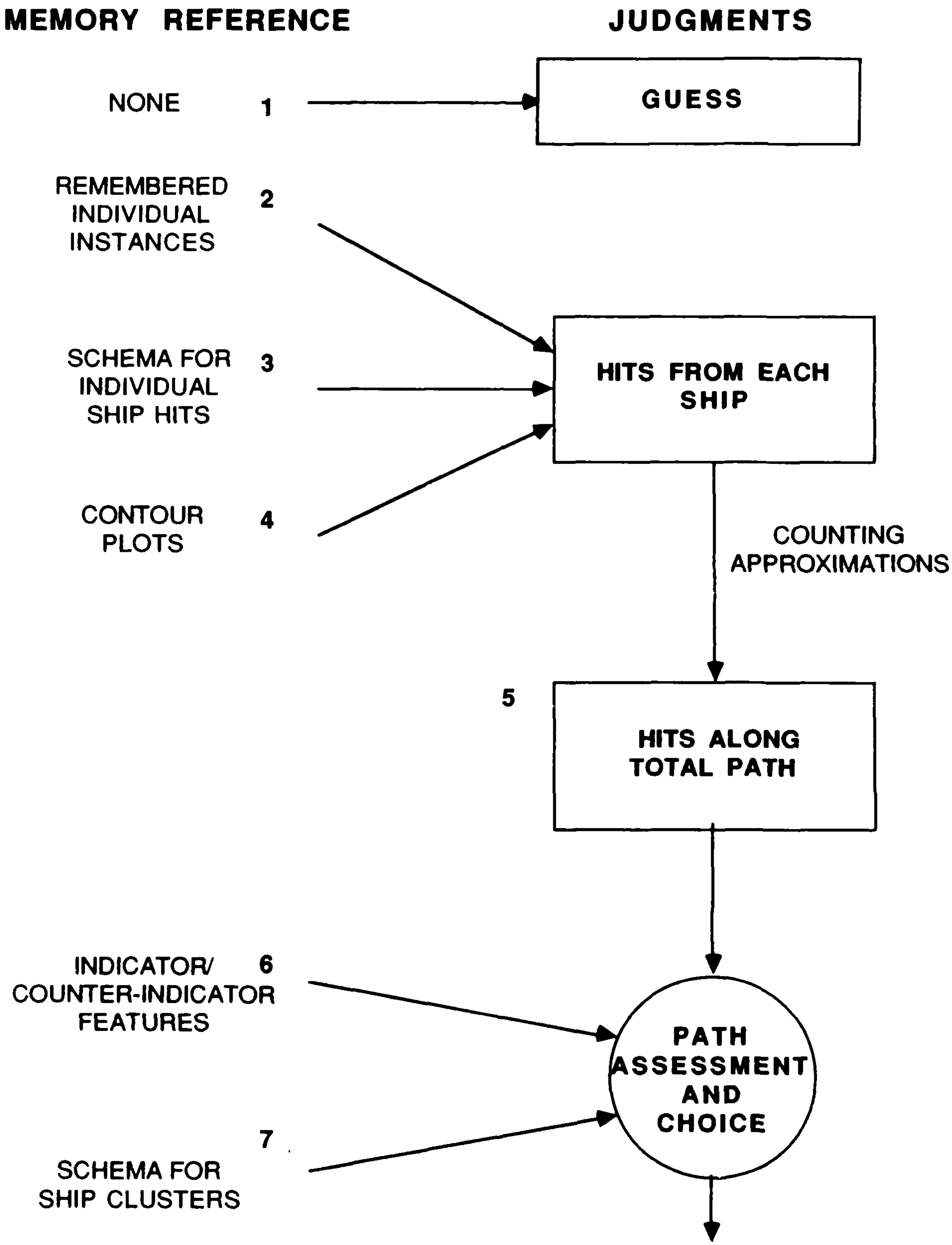


Figure 6-1: Investigated memory structures that might explain decision making performance.

of the process: 1) estimating the number of hits from ships, and 2) selecting among the alternatives (straight path, curved path, or stay).

The data indicate that in these tasks people employ both schemata and outcome calculation methods. They use the fuzzy set schemata of the kind illustrated in Figures 3-4 and 3-6 for estimating ship hits, and then evaluate the alternatives by summing these estimates of individual ships. The subjects did not use indicator/counterindicator features to bypass estimating hits along each path when making their decisions. There is highly suggestive evidence that people do not have or use contour-like discriminators in estimating ship hits. Finally, there is strong evidence that these subjects did not develop "wholistic" path schemata for path evaluation. These conclusions, and the most important data supporting them, are summarized in Tables 6-2 and 6-3.

CONCLUSION	REASONS
1. Subjects developed memory reference data to help them estimate ship hits.	1. Ship hit estimates made without measuring tools are much better than random. (1), (2)
2. Subjects use more than just the location of remembered instances in making their assessments.	2. Subjects' estimates of hits from ships distant from previously observed ships can be as accurate as their estimates of ships near those of previously observed ships. (1)
3. Subjects use schemata like those in Figure 3-4 for estimating hits from individual ships. Schemata are organized around the location of previously observed ships. They contain data for estimating changes in hits resulting from small changes in ship location.	3. Subjects' estimates of ship hits from ships equidistant from target points are equally accurate, whether ships were previously seen or not. (1) Estimated number of hits increases with distance from origin, and decreases with distance from path. (2)
4. Subjects do not have accurate contour like discriminators that separate the sets of ships able to score zero, one, and two hits.	4. Contour plots can be drawn, but are not drawn very well. Contour size and general shape are often highly inaccurate. (1) (2) Ship hit estimates predicted from subjects' drawn contours are usually significantly different from their estimates provided directly (2). Subjects provided with ground truth contour curves during training did not estimate ship hits more accurately than subjects not provided with these curves. (2)

Table 6-2 Summary of conclusions about subjects' use of memory structure to estimate hits from each hostile ship. Support attained in experiment 1 denoted by (1); support attained in experiment 2 denoted by (2).

CONCLUSION	REASONS
1. Path ranking is based on the sum of estimated ship hits.	1. Consistency of path ranking with rankings predicted from ship hits estimates is as high as path ranking test-retest consistency (which reflects individual ship hit test-retest variability). (2)
2. Subjects did not use indicator/counterindicator features.	2. Subjects provided with explicit features useful for path ranking did not notice nor use these features. (1)
3. Subjects did not use path schema to rank paths.	3. Wholistic assessments of path quality do not predict subject's path rankings as well as do subject's ship hit estimates. (2) Training method that encourages wholistic pattern recognition did not change relationship between hit estimates, path quality rankings, and path rankings . (2)

Table 6-3 Summary of conclusions about subject's use of memory structures to rank paths. Support attained in Experiment 1 denoted by (1); support attained in Experiment 2 denoted by (2).

6.3. Generality of results

Earlier research by Engineering Research Associates showed that the fuzzy schema model could explain a subject's evaluation of situations in terms of objective features of the situation. The subjects in those experiments were trained by examples explained in terms of situation features. In contrast, the experiments reported here sought to determine whether such schemata would form and be used by subjects when they were trained to evaluate decision alternatives using an analytical outcome evaluation process. The data indicate that subjects will develop and use such schemata, but that these schemata may support evaluations used in steps of the analytical processes rather than directly supporting the overall process. These subjects integrated both schemata and outcome calculation in their overall decision process. Furthermore, the type of schemata that developed did not vary with training condition, although the rate of schemata development did. It seems likely to us that these observations will be true in many decision tasks. In particular, it is likely (1) that with experience schemata will form to assist with the decision process, (2) that the the fuzzy schemata observed here may be the usual type that forms regardless of training method, and (3) that these schemata can be integrated with outcome calculation in various decision making strategies.

6.3.2. Type of schema

The schemata proposed to explain our data have several general properties that may characterize schemata used in situation assessment and decision making:

1. The schemata are organized around a prototype, a typical example of a type of situation. In our experiments, these were the ships observed during training.
2. The schemata define the features that are relevant for assessing situations modeled by the schemata. For ship hit schemata of Experiment 1, proposed features are the radial and angular displacements of the new ship from the previously seen "prototype" ship. For ship hit schemata of Experiment 2, proposed features are the vertical and horizontal displacements of the new ship.
3. The schemata contain "feature evaluation data" that enable people to evaluate the significance of differences between an observed situation and the typical prototype situation.
4. The schemata associate judgments with situations modeled by the schemata. For ship hit schemata of Experiment 1 and 2, these are the number of hits by a hostile ship at a target point and along the paths.

In addition to the properties listed above, decision oriented schemata may have the following characteristics:

1. The feature evaluation data may be organized as schemata themselves. Thus, the overall schemata for evaluating a situation may more accurately be regarded as a network of embedded schemata. This property of schemata have been documented by numerous investigators. (Rumelhart, 1981; Bower, Black, and Turner, 1979)
2. The features may be more abstract. The feature identification layer of the schemata may identify functional as well as physical properties of situations relevant to situation assessment.
3. The schemata may be "built on the fly." Schemata may not exist in long term memory. Rather they may be developed as needed from data in long term memory. The schemata then function to evaluate observed situations by comparing the properties of observed situations with expectations specified by the schemata.

The first two characteristics of schemata were observed in the earlier Engineering Research associates investigations. That last property is hypothesized to conserve memory requirements in long term memory. The data on conjunctive fallacy (Tversky and Kahneman,1983) and on jurors' evidence evaluation (Pennington and Hastie, 1986) also suggest this mechanism. It is not known how schemata are built in order to process a decision task.

6.3.3. Effect of training and experience

We also conjecture that schemata are the foundation for expert decision making. We believe that with experience people will develop schemata that enable them to identify high quality alternatives directly from the characteristics of the situation. Such schemata are proposed to account for the high quality of alternatives considered by chess masters (Chase and Simon, 1973).

Although the ship hit schemata were not examined in detail in the second experiment, the data from this experiment suggest the same type of fuzzy schemata will develop with each of the three training conditions. If so, then such schemata may represent a preferred or "natural" memory structure for schema-based decision making. Although training method may not affect the type of schemata that eventually develop, training method is likely to affect the rate at which they form. Given the characterstics of these schemata, they might develop most easily given training conducted in the following manner:

1. The training begins with a description of typical situations in which various judgments and actions are warranted.

2. Training continues with theory. The theory explains why particular kinds of actions are recommended for different kinds of situations. The theory may include outcome calculations and may include causal relationships linking situation features with actions outcomes.

3. Another phase of training provides examples of situations that vary from the typical situations described earlier. Each of these variations is related to a schema feature. The training emphasizes how the variation affects the judgments that should be made and the actions that should be taken. The training should also specify in terms of the theory why such variations have their effects.

6.3.4. Hybrid decision strategies

The decision making strategy observed in these experiments contained elements of both schema-based and outcome calculation decision making. Such hybrid strategies are likely to be common. The extent to which these two elements arises in any decision will depend on the characteristics of the task, the familiarity of the decision maker with the task, the severity of consequences for bad decisions, and preferred decision modes specific to the individual decision maker.

Because many decisions are likely to be based on both schemata and outcome calculation, and because the roles of these two processes will depends on numerous task and decision maker characteristics, it is not meaningful to ask whether a decision was based solely on schemata or whether it was based on outcome calculation. It will often be based on both. It is meaningful, however, to ask under what conditions these different processes are used, how they interact when both contribute to a decision, and how the processes affect the quality of decisions.

6.4. Implications for distributed decision making

Distributed decision making depends on different people making similar interpretations of situations and having a common understanding of the actions to be taken in these situations. It also depends on the decision makers identifying information which is most important to seek and communicate.

These research results suggest a particular kind of memory organization may mediate decision making in which situation recognition is important. Training and information presentation methods designed to interact with memory organized in this fashion may enable people to learn more easily how to interpret situations. These methods, if applied to groups of people, may

enable them to interpret situations more uniformly. Schema motivated training procedures were described earlier.

The schema theory also suggests information presentation methods. These methods make explicit in a display the schema in memory that are used for situation assessment. These displays show two types of information: schema derived situation reference data and data describing a current situation. The schema derived information emphasizes those situation features identified by the schema as relevant for assessing a situation. It also shows the significant deviations between the observed situation and the situation prototype.

The schema displays help identify important information to seek and communicate by indicating which currently ambiguous situation features might, when clarified, significantly affect the situation interpretation.

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APPENDIX A

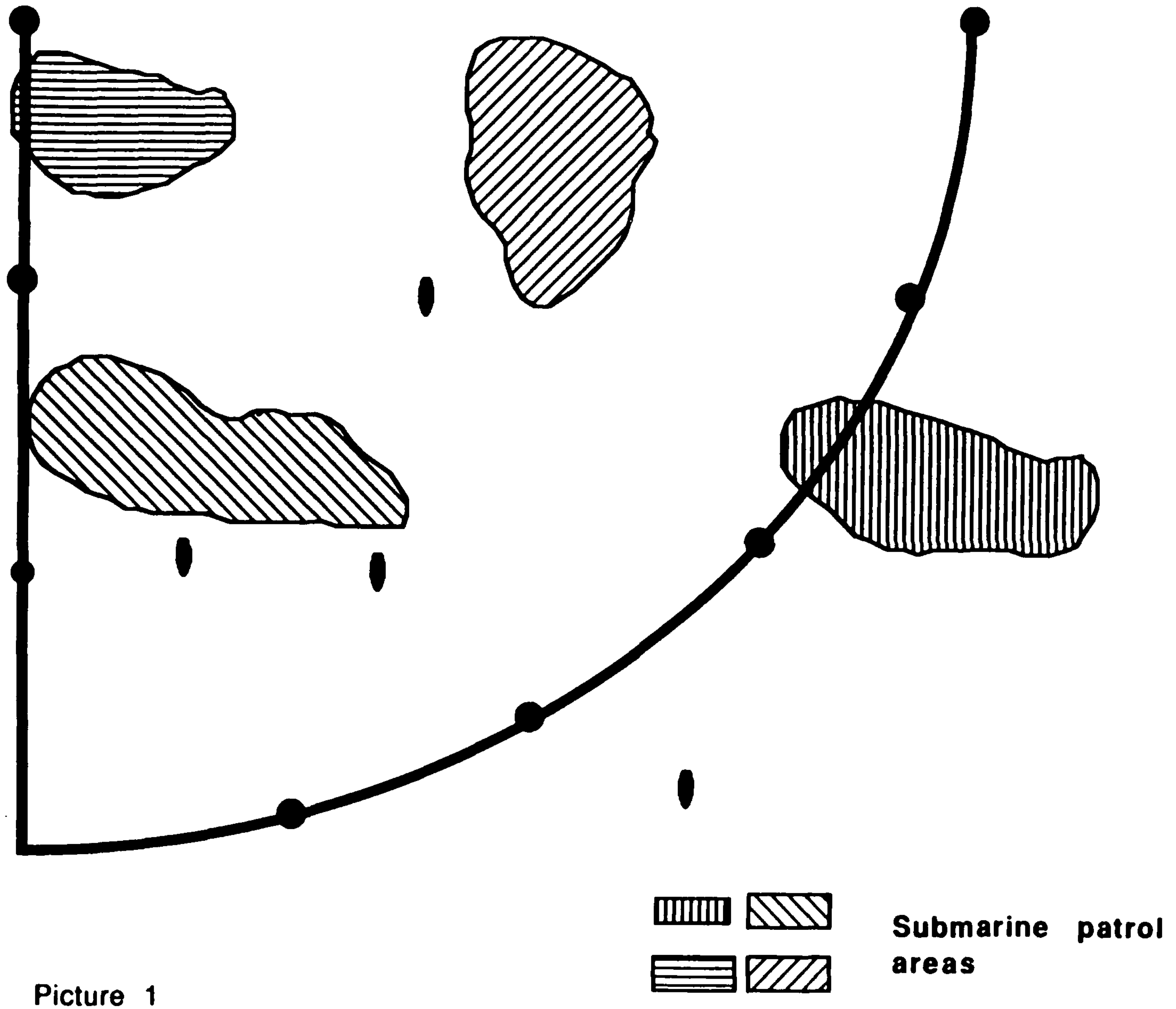

Figure A-1: Sample picture with single ship outside curved path (Experiment 1).

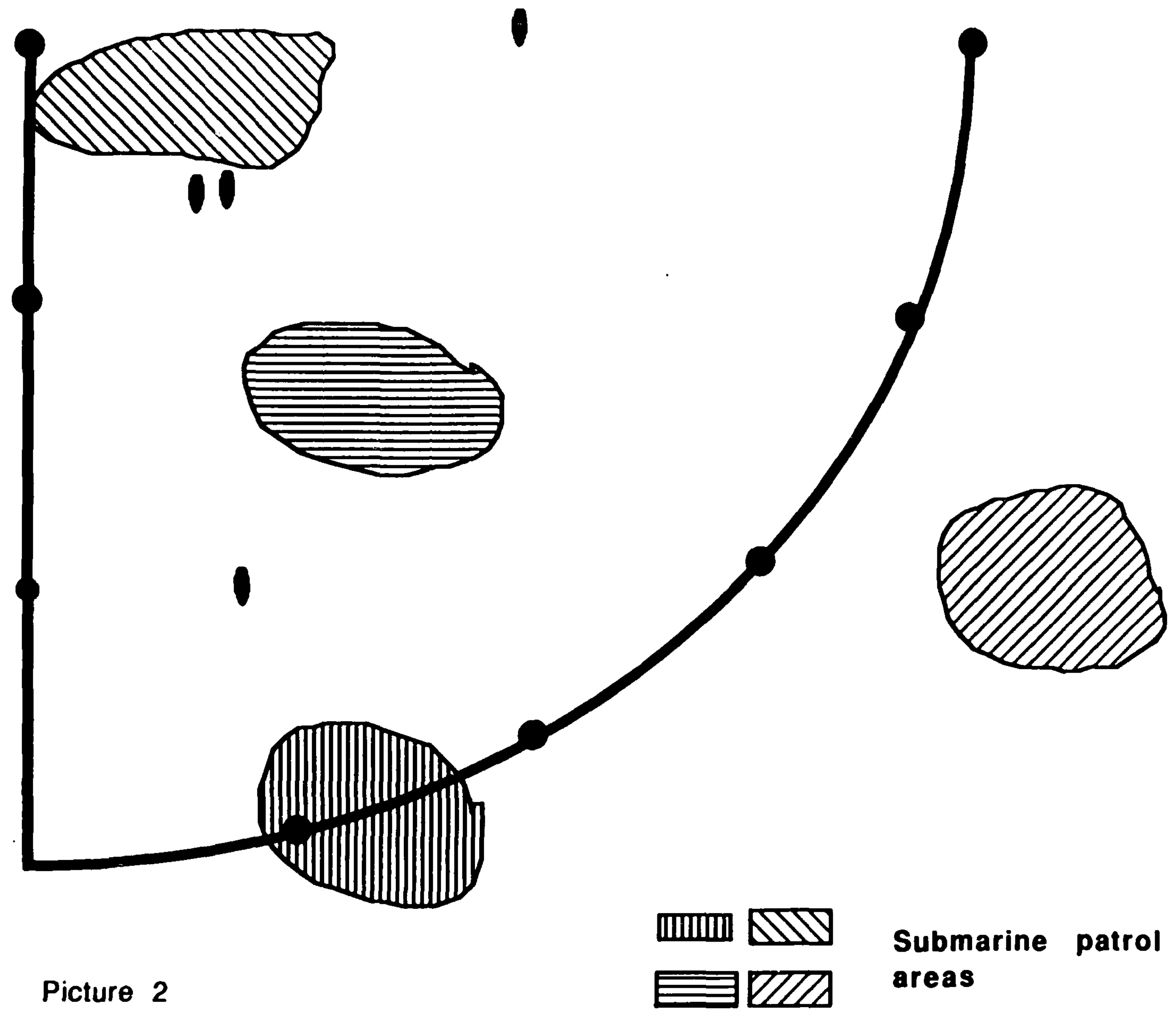

Figure A-2: Sample picture with pair of ships near end of straight path (Experiment 1).

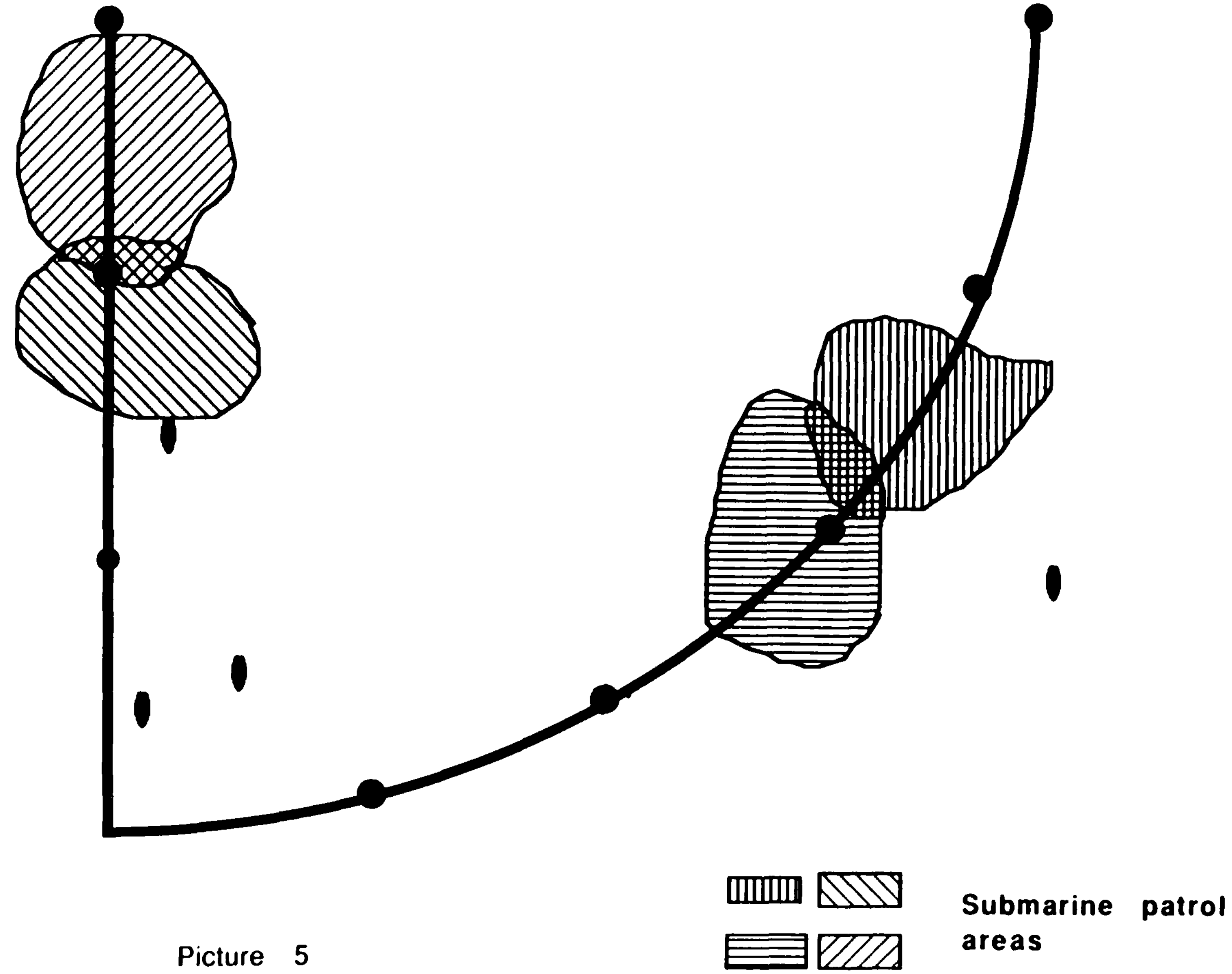

Figure A-3: Sample picture with overlapping submarine areas (Experiment 1).

APPENDIX B

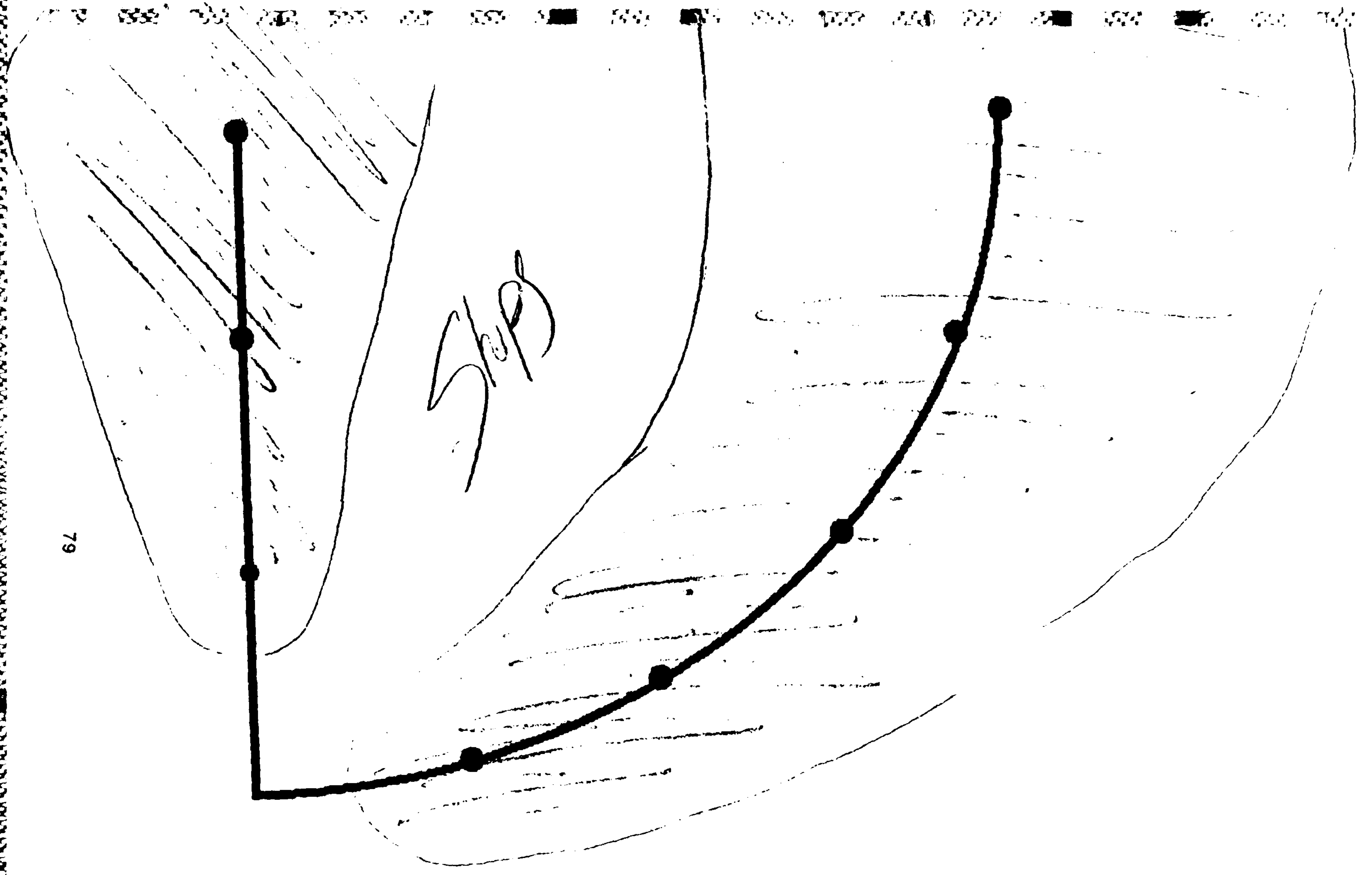

Figure B-1: One subject's representation of area from which ships can score hits (Experiment 1).

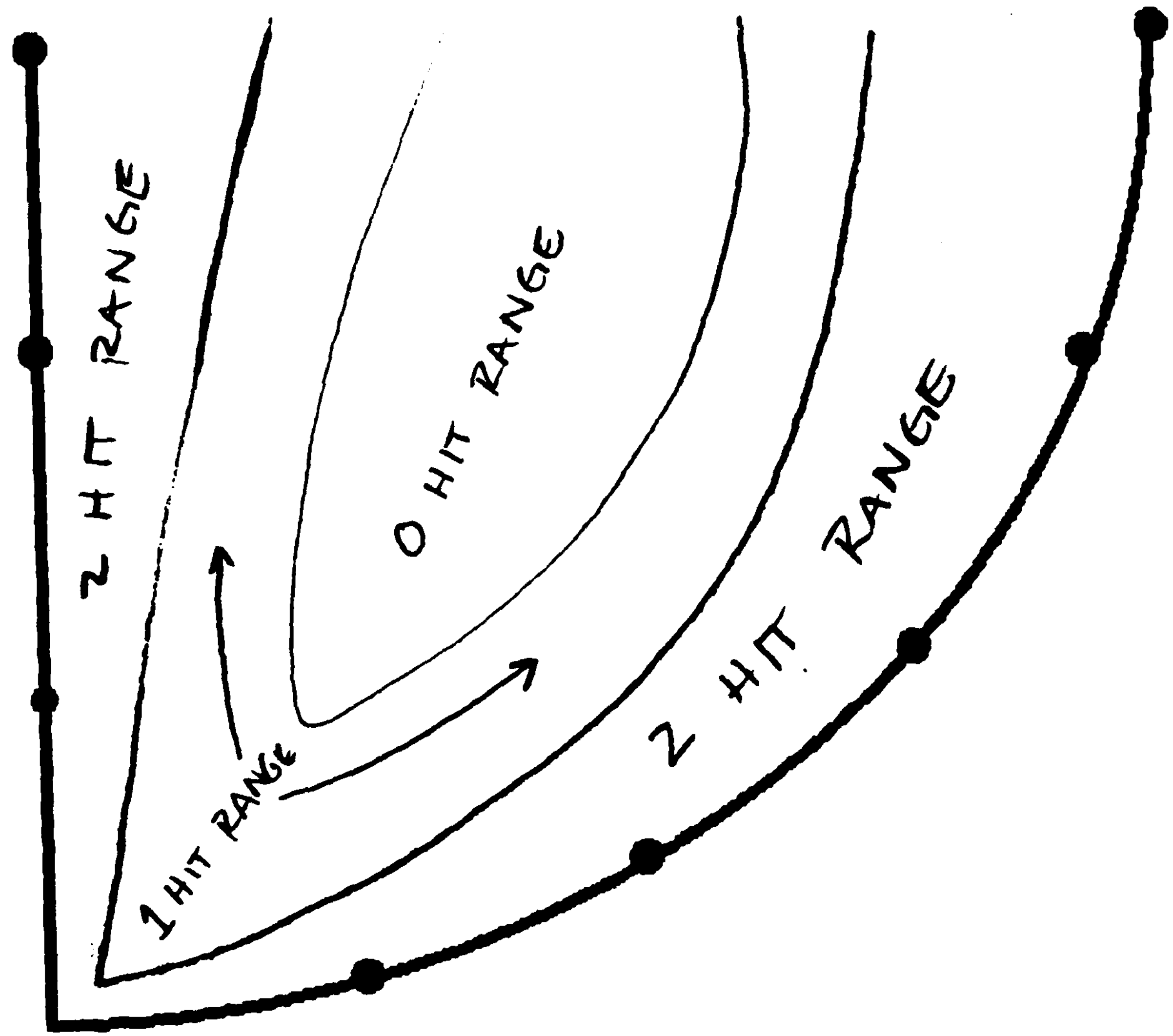

Figure B-2: One subject's representation of area from which ships can score hits (Eperiment 2).

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